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REPORT ON

FEASIBILITY OF DETERMINING SO_2 MASS EMISSION FLUXES BY STACKSCANNING

FOR

ONTARIO MINISTRY OF THE ENVIRONMENT
AIR RESOURCES BRANCH

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by
MONITEQ LTD.
CONCORD, ONTARIO

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1.0 INTRODUCTION

At present, the determination of SO_2 emission levels from stacks or other isolated combustion sources is usually made from in-stack measurements and/or from mass balances based upon fuel sulphur content. Regardless of the actual accuracy of these techniques, it is also desirable to have an independent method for making such measurements. A measurement which could be made remotely offers the added benefits of not impacting upon plant operations and not necessarily requiring the cooperation of the operator of the stack. Additionally, the measurement could be made rapidly at the discretion of the operator and in most cases from outside the plant boundary.

The following report details the results obtained from a study designed to assess the feasibility of using the MONITEQ Plumetracker to make such a measurement from a fixed platform. The study was supported by the Ontario Ministry of the Environment whose assistance and support is gratefully acknowledged. MONITEQ also acknowledges the assistance of Ontario Hydro on whose property the study was conducted.

2.0 STUDY OBJECTIVES

The primary objective of the study was to assess the feasibility of using the MONITEQ Plumetracker from a fixed platform to directly measure the SO_2 emissions from a stack. Initially the project was designed to study the effects of various parameters such as plume opacity, plume temperature and background sky conditions on the accuracy of the measurement. This was to be accomplished using a test stack for which certain parameters such as plume opacity and SO_2 concentration could be controlled and independently measured. Other parameters such as background sky conditions and sun angle were to be studied by selecting appropriate days or times at which to conduct the measurements.

Following a preliminary investigation of these parameters, the Plumetracker was to be used to make measurements on actual industrial stacks. The purpose of which was to confirm its operation in an industrial setting and to uncover any other parameters which might affect the accuracy of the measurement. Unfortunately, due to a number of unforseen difficulties and inclement weather conditions this objective was not realized.

The final objective of the study was to determine and specify any design changes which would be required in order to optimize the performance of the Plumetracker as a fixed platform remote sensor for SO_2 stack emissions. The design improvements uncovered during this study are detailed in the report recommendations.

3.0 EQUIPMENT DESCRIPTION

3.1 Plumetracker

The Plumetracker is a remote sensor designed to simultaneously measure ambient burdens of SO_2 and NO_2. Utilizing the sun as the source of UV radiation, the measurement is achieved by measuring the absorption of SO_2 and NO_2 at specific wavelengths. The wavelength chosen is one at which the target gas has strong absorption, yet absorption by other pollutants is virtually non existent. Changes in the source intensity are compensated for by also measuring the intensity of radiation at nearby wavelengths known to have little absorption to the target gas. This process is known as modulation spectroscopy.

Light is gathered in a 60 mrad by 1.6 mrad field of view which is defined by the entrance slit. The light enters the heart of the instrument, the grating spectrometer, and through a series of mirrors is imaged onto the exit slit mask. Two exit slits per gas are arranged to monitor an adjacent maximum and minimum in the absorption spectrum. A rotating aperative mask alternately passes the light from each slit on to the photomultiplier tube.

The signals from the photomultiplier tube are processed by analog electronics to produce a voltage which is proportional to the gas concentration within the field of view. An automatic gain control (AGC) ensures that variations in the intensity of the radiation are compensated for. A more detailed discussion of the Plumetracker operation and its normal applications is included in Appendix I.

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For purposes of this study it was necessary to modify the Plumetracker in a number of ways. Firstly, the proposed method of operation required that the field of view of the Plumetracker, nominally 1.6 by 60 mrad, be such that the larger dimension was orientated in a horizontal axis while the narrower dimension be located on the vertical axis. To avoid complicated and costly physical modifications this objective was achieved by simply rotating the entire instrument by ninety degrees thereby operating it on its side. In order to properly support the Plumetracker in this configuration a wooden housing was constructed.

Secondly, in order to support the instrument on a tripod it was necessary to attach a load bearing support plate to the Plumetracker which in turn was attached to the tripod. This allowed the Plumetracker to be positioned in a manner which made it possible to scan either in a vertical or horizontal direction.

The third modification was the addition of a telescopic sight through which the user could view the intended target. The telescope was aligned to match the normal field of view of the Plumetracker. Unfortunately, because of field of view differences between the Plumetracker and the telescopic sight, an exact match was not possible.

3.2 Continuous Emission Monitor

The continuous emission monitor (C.E.M.) utilized during this study was provided by the Ministry of the Environment. The measurement principle of the analyzer is based upon the principle of SO_2 absorption of infrared radiation. The instrument was equipped with a CO_2 filter and a ten centimeter measuring cell capable of concentration measurements from 0 to approximately 3000ppm.

3.3 Test Stack

The test stack was also provided by the Ministry of the Environment. The stack is part of a trailer mounted system normally used for opacity measurement training. In addition to the twelve foot high, one foot diameter stack, the trailer was equipped with a fan capable of delivering a stack output air flow of approximately twenty feet per second. The fan draws the air into the stack through a burning chamber which can be used for the controlled burning of fuels to produce plume Opacity. The stack is equipped with an opacity monitoring system, the output of which is displayed on the control console.

3.4 Data Recorders

Data generated by the C.E.M. was collected on an ordinary strip chart recorder. The output of the C.E.M. was a simple 0 to 10 volt analog output which was directly proportioned to the SO_2 concentration measured.

The data generated by the Plumetracker was collected by an HP-85 computer which automatically stored the raw data on to tape. Special data acquisition and processing programs were written to assist in the data analysis.

4.0 PLUMETRACKER MEASUREMENT PRINCIPLE

4.1 Concentration Units

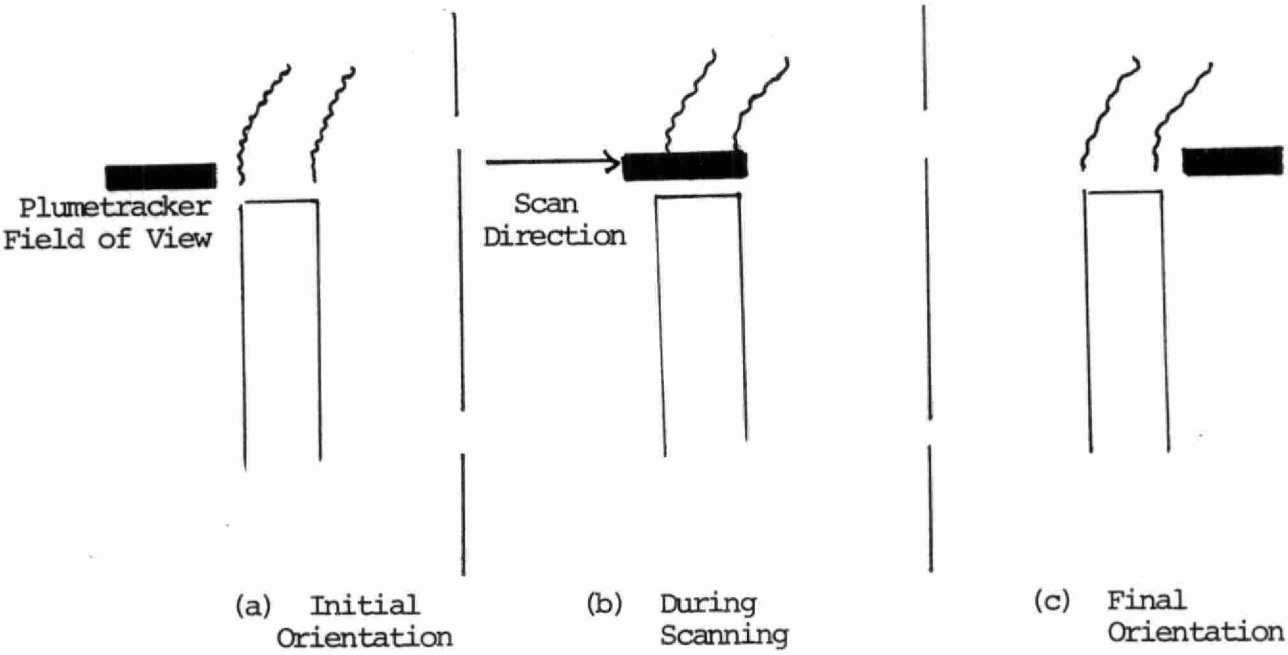
The theoretical principle of measurement of the Plumetracker has previously been discussed and is further detailed in Appendix I. Simply stated, the Plumetracker makes a measurement of the SO_2 concentration by measuring the absorption of U.V. radiation due to SO_2 within its field of view at a specific wavelength. The units of measurement are commonly expressed as parts per million-meter (ppm-M). That is, the measured absorption due to SO_2 is equivalent to the absorption by a specific concentration of SO_2 (expressed in ppm) contained within a path length of unity (one meter). For this study, in which the path length of the SO_2 is fixed and known to be approximately equal to the averaged stack diameter, the actual averaged stack gas concentration can be calculated by dividing the Plumetracker reading by the integrated stack diameter. The specific calculations are detailed later in this section.

4.2 Scanning Technique

There are two possible alternatives to measure stack concentrations using the Plumetracker from a fixed platform. The first is to initially align the Plumetracker field of view (FOV) such that it is viewing an area next to, but not including, the plume. The instrument can then be scanned in a horizontal direction so that the plume enters the FOV and continues through the FOV until it exits the opposite side. This method is illustrated in Figure 1.

The difficulty with this type of approach is that the scanning rate must be held constant throughout in order to obtain an accurate integrated measurement. Although this is feasible using a motor driven platform a second, technically easier alternative, exists.

FIGURE 1: Illustration of Scanning Technique

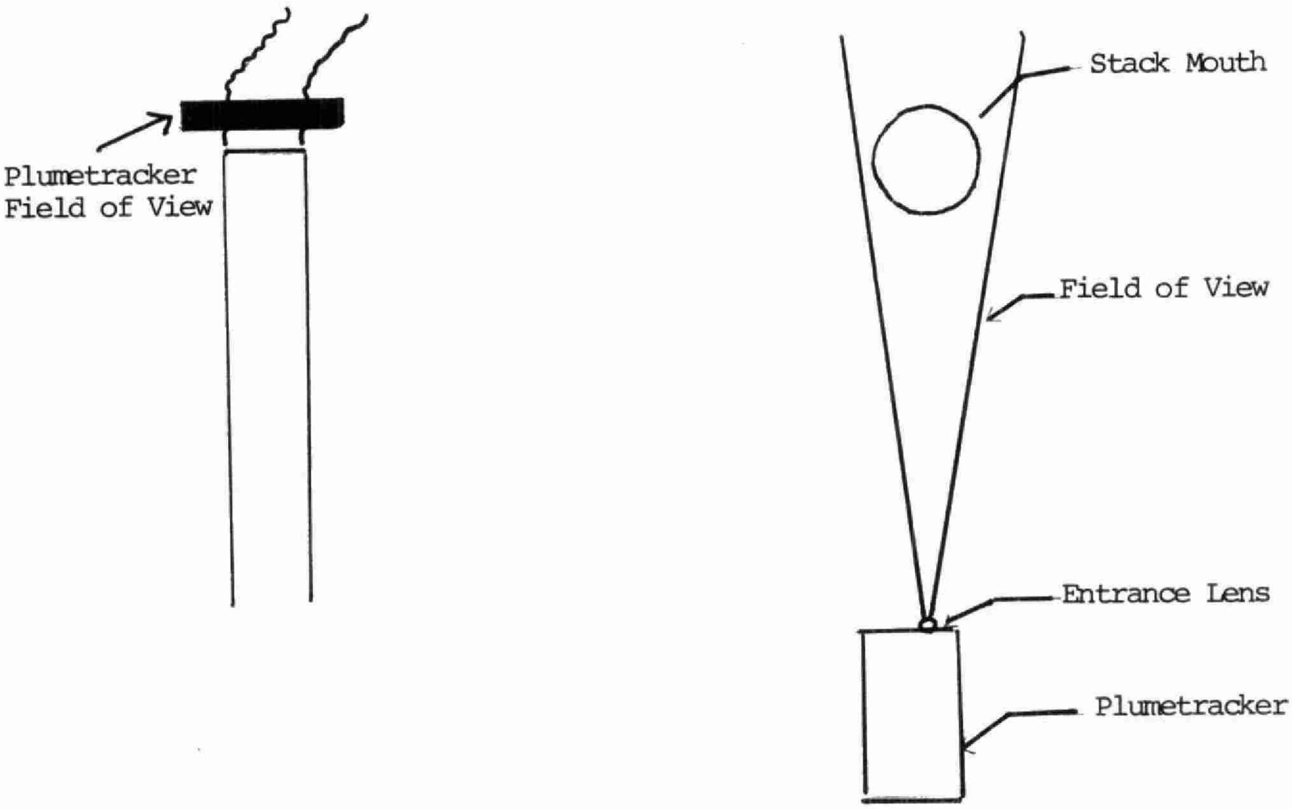


4.3 Stationary Technique

The second alternative and the one chosen for this study involves positioning the Plumetracker such that the entire plume is contained within the field of view. This arrangement is illustrated in Figure 2. The advantage of this method is that there is no scanning required and the arrangement can be used to monitor the output flow over long periods without having to stop measurement.

The initial zero level measurement can be obtained prior to the plume measurement by positioning the Plumetracker FOV outside of the plume as in Figure 1a.

FIGURE 2: Illustration of Stationary Technique

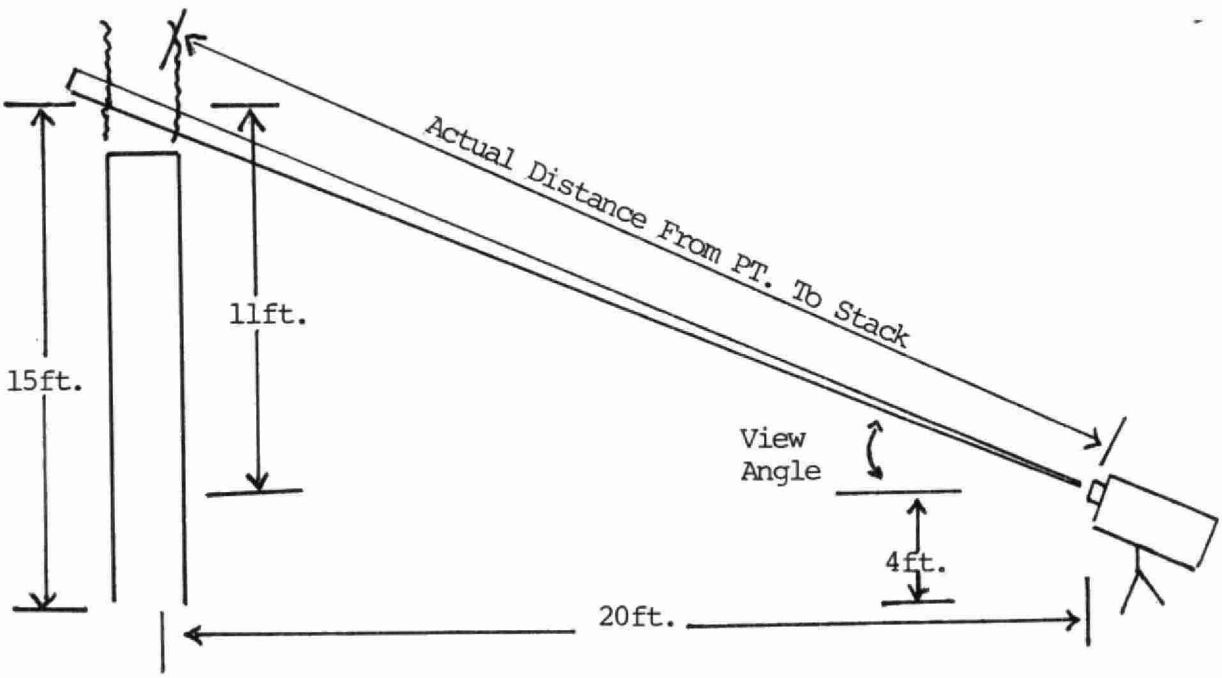


(a) Side View (b) Overhead View

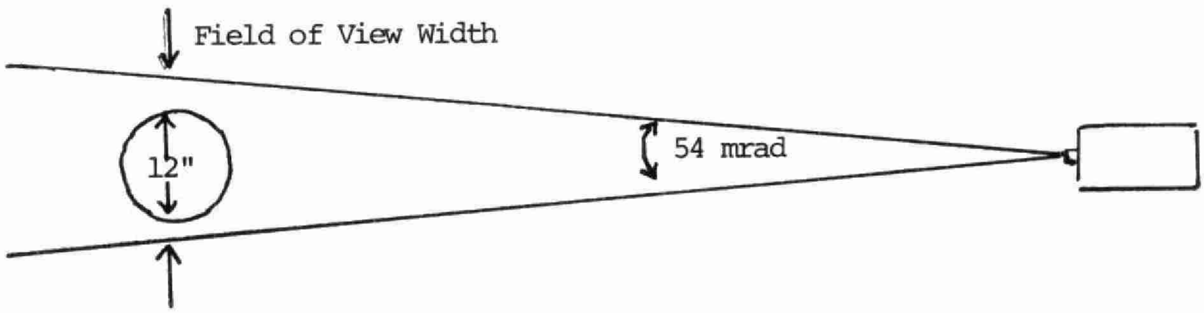
4.4 Calculation of Plume Concentration

Previously in this section it was stated that the actual average plume concentration of SO_2 could be calculated by assuming that the plume diameter is equivalent to the stack diameter. Figure 3 illustrates a typical field study arrangement and is provided to help simplify the explanation of how the calculation is performed. The actual calculations were performed in the data processing program .

FIGURE 3: Typical Field Study Arrangement



a) Side View



b) Overhead View

The first step in the calculation is to obtain the average integrated measurement of the plume SO_2 concentration. As has been stated, this is obtained by measuring the Plumetracker voltage output and comparing the value to the laboratory calibration of the sensor. The result is a concentration measurement in units of ppm-M of SO_2.

The next step is to correct this value for the field of view coverage. From figure 3 (b) it can be seen that the plume does not occupy the entire field of view of the Plumetracker. The actual field of view can be calculated from knowing the horizontal distance between the Plumetracker and stack (20ft.), the height of stack above the Plumetracker (12ft.) and the known F.O.V. of the Plumetracker (54 mrad). The resultant value represents the reading which would have been obtained had the plume exactly covered the entire field of view.

The third step in the calculation is to correct the value to compensate for the view angle of the Plumetracker. The view angle will determine the actual path length at the plume centre line. The value is corrected to yield the reading which would have been obtained if the Plumetracker view angle had been zero degrees.

The final step is to determine the actual plume concentration by dividing the corrected value by the average path length expressed in meters. In the case of circular stacks having diameter 'D' the divisor is simply $1/4\pi D$. The resultant value represents the true average SO_2 concentration (expressed in ppm) as it was measured by the Plumetracker.

If the Plumetracker is aligned such that it views the plume just above the mouth of the stack, the assumption of the plume diameter is valid and the measured value will be representative of the actual in stack SO_2 concentration.

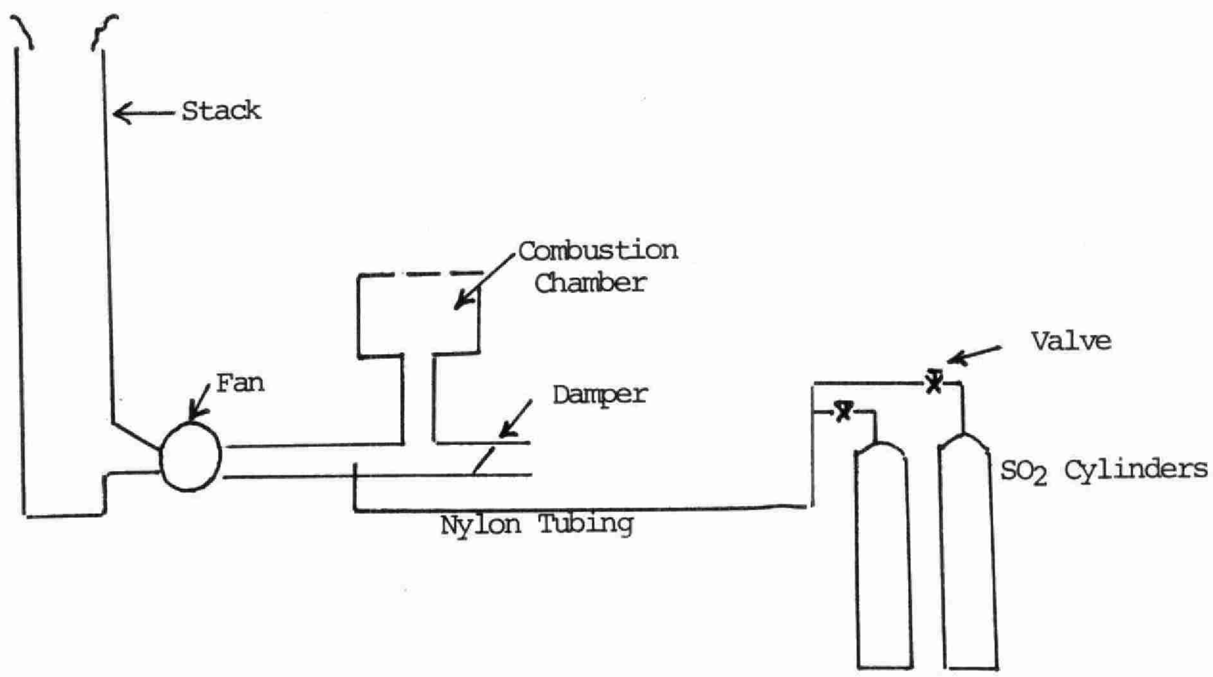
5.0 STUDY METHODOLOGY

5.1 Stack SO_2 Concentration

The desired stack SO_2 concentrations were obtained by injecting pure SO_2 gas into the air intake system of the stack. Figure 4 illustrates the experimental arrangement.

The SO_2 was obtained from pressurized cylinders containing liquid SO_2. The flow rates of the SO_2 streams and consequently the SO_2 stack concentrations were controlled using needle valves at the outlet of each cylinder. The gaseous SO_2 was injected into the air intake system upstream of the exhaust fan. The SO_2/air mixture was then mixed by the fan and then directed out through the stack.

FIGURE 4: SO_2 Injection System



5.2 Plume Opacity

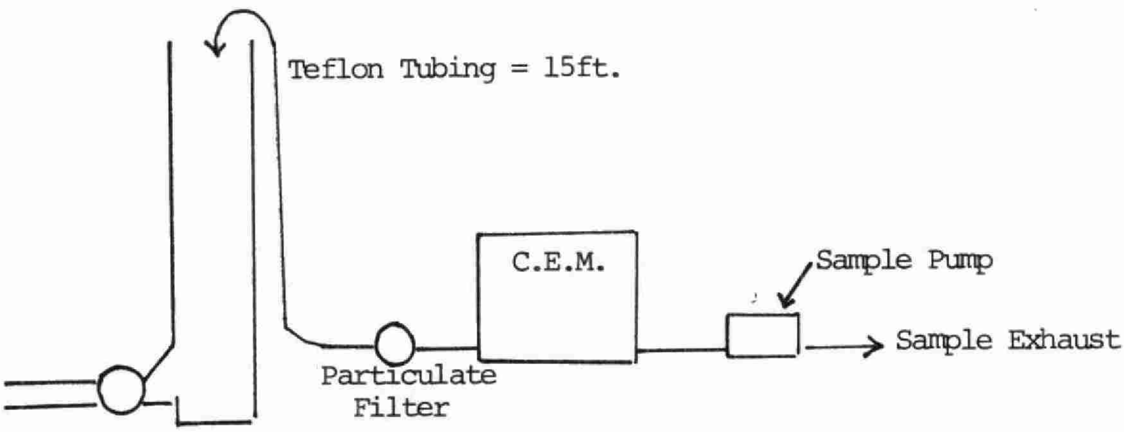
Plume opacity was achieved through the controlled burning of toluene inside of the combustion chamber. The rate at which toluene was fed into the chamber determined the opacity of the plume. The rate was controlled via a needle valve located downstream of the pump. The products of the burning were mixed with the air being drawn into the system and eventually the mixture was exhausted out through the stack.

5.3 CEM-Stack Sampling Arrangement

The SO_2 concentrations exiting the stack were measured using a continuous emission monitor. The experimental arrangement is shown in Figure 5.

The CEM was positioned on the trailer which held the test stack. The air to be sampled was drawn through the measuring cell of the CEM by a small pump. The sample intake port was located at the top of the stack near the centre line.

FIGURE 5: CEM Stack Sampling Arrangement



5.4 Plumetracker Sampling Procedure

The orientation of the Plumetracker with respect to the test stack is illustrated in Figure 3. Prior to each survey the Plumetracker was positioned such that it was viewing the plume at an angle perpendicular to the wind direction. The view angle being fixed by the distance between the Plumetracker and the test stack.

To simplify the data acquisition procedure, background zero levels were obtained by simply shutting off the flow of SO_2 to the stack. This made it unnecessary to re-align the Plumetracker after each reading.

Data acquisition was controlled through the HP-85 which also stored the data on to tape for later processing. A sample of processed data is included in Appendix II .

6.0 INITIAL PREPARATION

6.1 Uniformity of Stack SO_2 Concentration

Initially a small test was undertaken to verify that the SO_2 injected into the stack was being thoroughly mixed with the air stream, thereby ensuring that the CEM readings were representative of the average SO_2 stack concentration. To verify this the sampling port was positioned in nine places at the mouth of the stack and the resulting SO_2 concentrations were measured. The results, illustrated in Table 1, show that the exit SO_2 concentration is reasonably uniform across the mouth of the stack.

FIGURE 6: Stack Sampling Positions

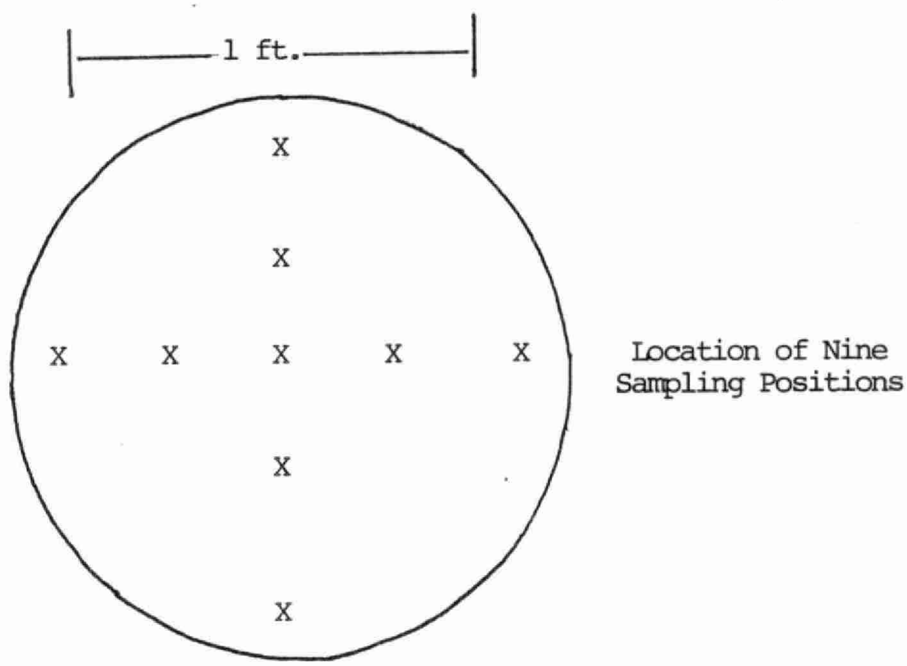


TABLE 1: Results of SO_2 Uniformity Test

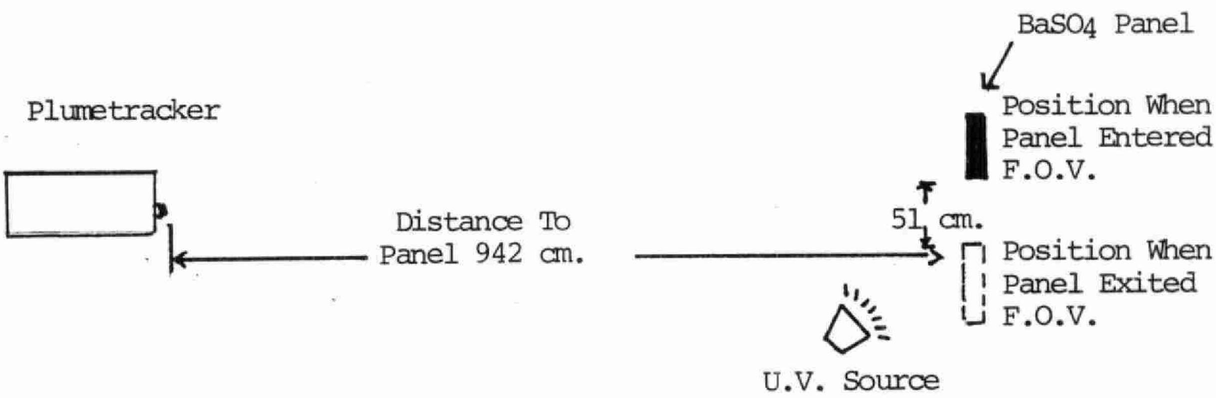
Sampling Position	SO_2 Concentration (PPM)
1	620
2	615
3	616
4	620
5	632
6	627
7	606
8	624
9	638

6.2 Determination of Plumetracker F.O.V.

Although the Plumetracker entrance slit has been designed to provide a field of view of 60 mrad the true field of view is dependant upon the actual optical alignment. To determine the true field of view the following experiment was conducted. The experimental arrangement is shown in Figure 7.

A high intensity U.V. source was directed at a $BaSO_4$ panel. The reflection of the U.V. radiation from the $BaSO_4$ panel provided a well defined source which was then used to map out the Plumetracker field of view. By monitoring the AGC level of the Plumetracker (the AGC level is a relative indication of the radiation reaching the photomultiplier tube) it was possible to determine the exact locations where the source entered and exited the field of view. From the dimensions indicated the field of view was calculated to be 54 mrad.

FIGURE 7: Determination of the Plumetracker F.O.V.



6.3 Plumetracker and CEM Calibration

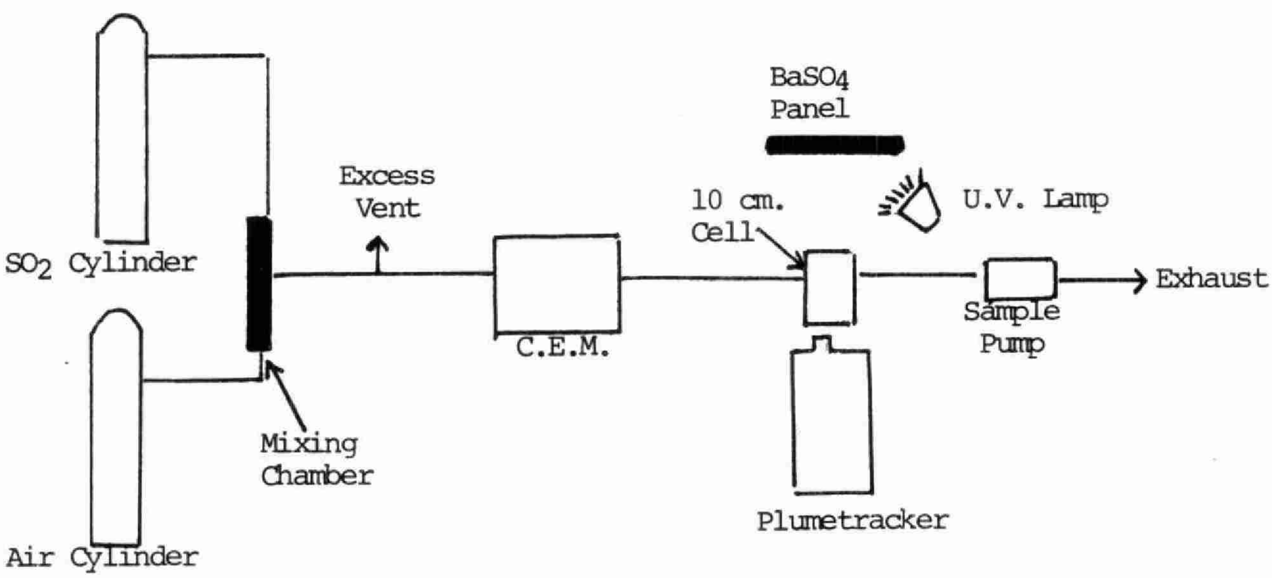
Prior to the actual field study it was necessary to calibrate both the CEM and the Plumetracker. The calibration of the CEM was performed in the normal fashion by dilution of pure SO_2 gas with dry air from a cylinder.

The Plumetracker was calibrated in a similar way, however the calibration mixture was allowed to flow through a 10 cm. closed cell which was placed in the analyzers F.O.V. The 10 cm. cell defines the pathlength thereby making it possible to calculate the concentration of the mixture. As an example, a 6000 ppm mixture passed through the 0.1 meter cell will have an effective concentration of 600 ppm-M. A high intensity U.V. lamp reflected off a $BaSO_4$ panel provided the background radiation source.

Following their individual calibrations both analyzers were connected in series to the calibration arrangement and their responses were compared. Figure 8 illustrates the calibration arrangement used for this purpose. The SO_2 is first mixed with the air and any excess flow is allowed to vent through the exhaust. The CEM sample pump is used to draw this calibration mixture first through the CEM for analysis and then through the 10 cm. cell for analysis by the Plumetracker.

Results of the calibration and the intercomparison are discussed and referenced in the following section.

FIGURE 8: Plumetracker/CEM Calibration Arrangement



7.0 SUMMARY AND DISCUSSION OF FIELD PROGRAM

To simplify the presentation of data, the data referred to in this and following sections has been placed in Appendix III. Tables and their associated graphs have been alpha numerically designated for ease of comparison.

7.1 CEM/Plumetracker Calibration-August 24, 1984

Prior to any measurements being conducted in the field, both the CEM and Plumetracker were calibrated in the laboratory. The results of the CEM and Plumetracker calibrations as well as the comparison calibration between the two are tabulated in Appendix III, Tables A, B, C and Figures A, B, and C respectively.

The laboratory comparison between the two analyzers, illustrated in Figure C, is quite good for the concentration range from approximately 800 to 2800 ppm. The scattering in the lower concentration range is likely due to the very low readings obtained from the Plumetracker. With the 10 cm. cell a 400 ppm calibration standard would yield a response of only 40 ppm-M. This is less than 2% of the Plumetrackers full scale.

7.2 Study Day No. 1-August 27, 1984

The results of the first study day are tabulated and illustrated in Table D and Figure D respectively. Generally the background sky was clear with only ocassional light cloudy patches. The wind was in excess of 25 Km. per hour and the air temperature was approximately 25 degrees C.

A number of unforseen but not unexpected problems delayed the start of the actual study. These included difficulties with the alignment of the Plumetracker with respect to the stack exit as well as output signal problems with the CEM. The number of valid data points is therefore quite limited.

In general, the results show an extremely poor correlation between the two analyzers. One factor which obviously contributed to the poor correlation was the small plume coverage of the Plumetracker field of view. With the plume only occupying about 13% of the FOV the resultant Plumetracker signals were very low even with relatively high stack concentrations. For example the highest stack concentration of approximately 800 ppm only resulted in a Plumetracker response of about 100 ppm-M, which is less than 5% of its full scale.

Another factor which was later found to contribute significantly to the poor correlation, was the high wind speed. This will be discussed further during the review of study day 3.

7.3 Study Day No. 2-August 29, 1984

The results of the second study day can be divided into three distinct groups. The first grouping of data was collected at a distance of approximately 20 meters from the stack. The second grouping represents data collected within 10 meters of the stack and the third grouping was collected at the original 20 meter location.

The objective was to study the effect of the field of view coverage on the results. The results for this day are presented in Table E and Figure E.

The conditions during the second day were similar to those experienced on the first day. The wind speed was in excess of 15 Km. per hour while the temperature was only slightly less at approximately 23 degrees C. The background sky was for the most part, evenly covered by a thin layer of clouds.

Similar to the first day the results show a poor correlation between the two analyzers. The correlation, however, appears to improve slightly as a higher percentage of the field of view is occupied by the plume. At 20 meters the plume covers about 30% of the FOV while the coverage increases to approximately 50% at 10 meters.

The major reason for the poor correlation was, however, probably due to the high wind speed. This factor is discussed more fully in the following section.

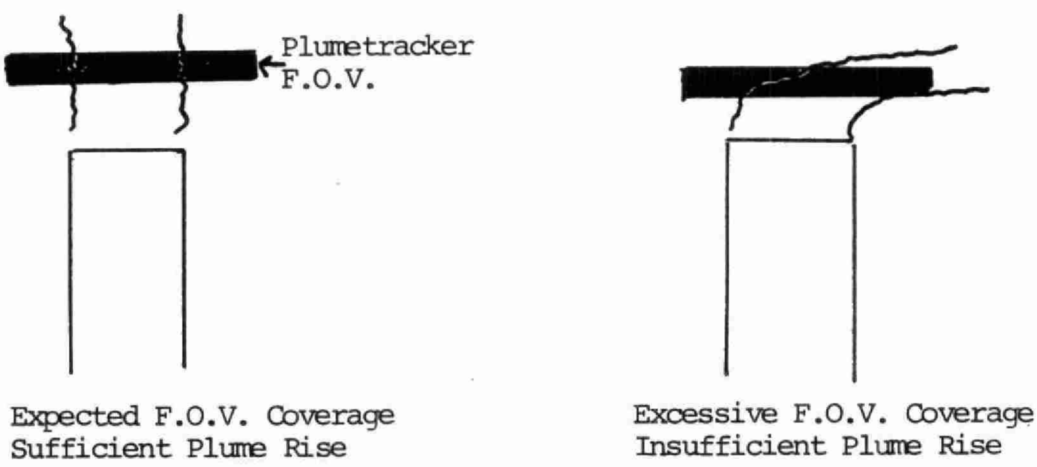
7.4 Study Day No. 3 - September 5, 1984

Based upon the results of the first two days it was realized that the plume had to occupy a significant portion of the field of view. The objective of the third day then, was to locate the Plumetracker near the stack to maximize the FOV coverage and study the affects of plume opacity. With the plume visible it was, for the first time, possible to see the effect of the wind upon the plume rise.

For the majority of the runs the plume rise above the stack was less than one or two inches. Quite often a significant portion of the plume was forced below the exit level of the stack.

Considering that the wind speed during the first two study days was greater than on the third, it is believed that the impact on the plume rise was even more severe. Figure 9 illustrates the effect that an unsuitable plume rise has upon the Plumetracker measurement. Portions of the plume are held in the field of view resulting in a higher absorption and therefore an abnormally high reading. The problem increases in severity as the percent coverage of the FOV by the plume decreases, i.e. at greater distances from the source.

FIGURE 9: Effect of Wind on Plume Rise



Based upon the observation that insufficient plume rise was obtained even during moderately windy conditions, it was decided to limit further studies to those ocassions when no wind was present. It was believed that the study could be performed early in the day when stable conditions prevailed.

The results obtained during study day #3 are detailed in Table F and Figure F. As has been stated the reason for the poor correlation is probably due to insufficient plume rise.

Throughout the study, difficulties were experienced in trying to maintain constant opacity levels for extended periods. The needle valve which controlled the flow of toluene and thereby the plume opacity was subject to vibration and required constant readjustment. For this reason the opacity readings have been sub-divided into just four classes; nil, low, medium and high. In this report a low opacity is defined as 10% or less, medium is between 10% and 20% and high is greater than 20%.

7.5 Study Day No. 4 - September 6, 1984

Data for the fourth study day were collected during generally low wind conditions. For the most part the plume rise was in excess of three inches and ocassionally up to six inches. Appendix II illustrates the effect of plume rise on the stability of the Plumetracker measurement. The data shown in Figure 10 was collected when the plume rise was in excess of nine inches for the entire run.

The result was an extemely stable measurement for the entire period. This can be compared to Figure 11 which represents the next run, in which the plume rise was unstable (zero to three inches) at the beginning of the run.

The data for the fourth day is detailed in Table G and graphically represented in Figure G. In summary, the data shows a strong correlation between the Plumetracker readings and the actual stack concentration. The relationship however is not one to one as would be expected and an intercept of 100 ppm-M is indicated.

During the fourth study day it was also possible to observe the detrimental effects on the Plumetracker signal caused by large white clouds passing quickly through the field of view. These observations were made late in the day when the upper wind speed had increased such that large cumulus clouds were rapidly travelling through the field of view. This rapid change in the background radiation caused a momentary upset in the Plumetracker signal. Further discussion of this effect is contained in the summary of parameters.

7.6 Study Day No. 5 - October 24, 1984

The objective of the fifth study day was to confirm the unexpected relationship discovered on the previous study attempt. Of particular interest was the intercept of 100 ppm-M which was to be verified by increasing the number of data points collected at the lower concentration levels.

Unfortunately difficulties were encountered with the CEM after having obtained only eleven data points all of which were at the lower concentration range.

Similar to the fourth study day the Plumetracker was positioned near the stack such that the plume occupied approximately 80% of FOV in addition, the plume opacity was maintained constant and at a low level such that the plume was just visible enough to confirm sufficient plume rise.

In order to collect the data during low wind conditions the study was initiated at approximately nine o'clock in the morning. At this time of day the background U.V. radiation was found to be slightly unstable. The constant increase in U.V. radiation, however, did not present any problems since it was possible to compensate for the increase by readjusting the gain of the Plumetracker AGC circuit. The adjustments do not affect the response characteristics of the instrument and it was, therefore, not necessary to re-calibrate.

The data collected during the fifth study day is presented in Table H and Figure H. In general the available data supports the previously observed linear relationship, however without higher concentration data being available it is difficult to draw any firm conclusions. Additionally, because of the low concentrations observed and the narrow stack diameter the highest Plumetracker reading observed was only 100 ppm-M which represents less than 5% of the analyzers full scale range.

7.7 CEM/Plumetracker Calibration - November 19, 1984

A recalibration of both sensors was undertaken at this time for three reasons. First, the unusual and unexpected relationship observed indicated that perhaps the response of one or both of the analyzers had changed since the August calibration.

Secondly, the aforementioned belief was strengthened by the fact that both of the field standards had not been included in the orginal calibration effort. The concentration of the field standards, one of which was used to verify the CEM response and the other the Plumetracker response, had been assumed to be the same as that listed on the original calibration performed some ten months earlier. The recalibration was therefore, required to verify the concentration of the field standards.

The third reason was that the full measurement range of the Plumetracker was not being utilized because of the small exit diameter of the stack. Even assuming 100% coverage of the FOV, the Plumetracker response to a stack concentration of 2000 ppm would be approximately 500 ppm-M or less than 20% of its full scale range. The recalibration effort would allow the Plumetracker to be adjusted to a more sensitive range. Although this adjustment could have been performed in the field, the response would have to be verified through a laboratory calibration.

The results of the calibration effort were detailed in Appendix III,Table I, J, K and Figures I, J and K. The results confirmed that the concentration of both field standards was virtually identical to the previously assumed values and that the response of both analyzers had not significantly changed since the August calibration.

The Plumetracker was adjusted to a more sensitive range with a full scale of approximately 700 ppm-M. This compares to the previous range of nearly 3200 ppm-M.

In addition, a comparison between the responses of both analyzers was again undertaken with similarily good agreement between the two.

7.8 Study Day No. 6 - December 18, 1984

Because of the infrequent number of days when nil wind conditions existed and the relatively short time before even these conditions deteriorated, the construction of a wind screen was undertaken. The screen consisted of a wooden frame six feet high by eight feet wide covered with a plastic sheet. The screen was supported on stilts and was positioned approximately three feet from the stack exit and high enough to allow for a plume rise of better than 10 inches. Although ineffective during winds in excess of approximately 15 Km. per hour the screen proved to be quite effective under most conditions.

The objective of the sixth study day was to confirm the previously observed relationship and determine the effect of plume opacity on the measurement. The results, which are detailed in Table L and Figure L, have been divided

into two groupings. Initially the data were collected with a plume opacity of between 10% and 20% (Medium). The second, group was collected with a plume opacity of zero.

Both groups of data show a strong correlation between the Plumetracker measurements and the stack concentration, however, as has been observed before, the correlation is not one to one and an intercept of approximately 100 ppm-M exists. A superficial examination of both data sets indicates that there is no significant difference between them.

It should be noted that other than the change in opacity and the time difference between the two sets all other parameters were common to both groupings. The importance of this observation is realized when it is noted that these two data sets are the only ones which are not significantly different.

Unfortunately, due to unfavourable winter weather conditions experienced after December 18, 1984, no additional study attempts were possible.

8.0 DISCUSSION OF PARAMETERS

8.1 Field of View Coverage

The obvious lack of repeatable results makes it difficult to draw any definite conclusions concerning the effect of the field of view coverage. In general however, the study showed that more consistant results were obtained when a high field of view coverage by the plume existed. There are two apparent reasons for this.

First, and most obvious, is that the field of view coverage is directly relateable to the amount of signal generated by the Plumetracker. The greater the coverage, the higher the absorption and therefore the greater the signal produced by the Plumetracker.

The second reason arises from the results obtained on windy days. It was demonstrated that a small field of view coverage increases the chance that excess of view causes abnormally inflated readings.

8.2 Sun Position in the Sky

Although not directly studied the effect of the sun position in the sky was observed throughout the study. The relative position of the sun affects the measurement in two ways.

First, and again most obvious, is that the height of the sun in the sky is directly relateable to the amount of available backround U.V. radiation. The amount of U.V. radiation is also dependant upon the cloud cover and will therefore be discussed in greater detail in that section.

The second effect is that in the early morning as the sun is rising the background U.V. radiation increases rapidly. The rapid increase did not however seem to affect the measurement since the time required for a reading was usually less than sixty seconds. The only noticeable impact was that the gain of the Plumetracker AGC circuit had to be readjusted frequently to compensate for the increased radiation levels. This readjustment was performed approximately every fifteen to thirty minutes, decreasing in frequency until around noon when the U.V. radiation level had stabilized.

The readjustment does not change the response of the analyzer and therefore the impact was minimal. The readjustment did, however require one to two minutes to complete. Newer Plumetrackers have a larger gain range and it is expected that the frequency of the readjustment would be less. In addition the adjustment potentiometer is located on the front panel of the newer Plumetrackers and the entire procedure can be completed within a matter of seconds.

8.3 Sun Position Relative to the Plume and Plumetracker

Because of the experimental arrangement relative to the Ontario Hydro station and the prevailing westerly winds, it was difficult to study a number of sun positions relative to the plume and the Plumetracker. The orientation of the test stack relative to the generating station made it impossible to conduct measurements with the Plumetracker viewing the southerly sky. This was of course due to the background contribution of SO_2 from the generating station.

In addition, the non reproducible results make it difficult to draw any definite conclusions other than to state that the non reproducibility is not likely due to the relative sun position. This statement is based upon the results obtained from study days four and six which were performed under identical sun conditions with differing results.

8.4 Effects of Clouds

Clouds were observed to affect the measurement in two ways. The first being that the clouds reduce the amount of available background U.V. radiation. Under most circumstances, where the cloud cover within the field of view was nearly uniform, this was not found to be a problem. The exception to this was when large cumulus clouds which moved rapidly through the FOV were present. This will be discussed later.

Under normal circumstances where the cloud cover has simply reduced the available amount of U.V. radiation, the reduced radiation can be compensated for by readjusting the gain of the AGC circuit. As was previously discussed this adjustment does not affect the response curve of the Plumetracker. The difficulty is encountered when the cloud cover has reduced the radiation to such a low level that it is below the minimum acceptable value. This situation is most common in the morning and during the winter months when the available U.V. radiation is at its lowest.

The second difficulty was encountered on days when large cumulus clouds were present and when these clouds moved rapidly through the field of view. The contrast in U.V. radiation levels between these clouds and the

clear blue sky was so great that the AGC (automatic gain control) circuitry could not properly compensate for the change in radiation levels. In these cases when a cloud moved rapidly into or out of the FOV the AGC was momentarily upset causing a false signal. The severity of the problem was variable since it is dependant upon the speed at which the clouds enter or exit the FOV and the contrast difference between the clouds and the background sky. Newer Plumetrackers are equipped with an LED which is activated whenever the AGC is upset in this manner.

8.5 Plumetracker View Angle

Since it was necessary to maximize the field of view coverage by the plume thereby fixing the view angle and because all measurements were made on the same stack, it was impossible to independently study the effect of the viewing angle.

8.6 Plume Temperature

Again, because of the inconsistant results obtained, it is difficult to draw any definite conclusions regarding the effect of plume temperature.

8.7 Plume Opacity

The only results which allow for conclusions regarding the effect of plume opacity are those obtained on the final study day. The data does, however, indicate that there is very little if any effect for plume opacities up to 20%. Again, no definite conclusions can be reached based upon the limited amount of data.

8.8 SO_2 Concentration

Except for the initial study days, all of the data indicates that a reasonable correlation exists between the Plumetracker readings and the plume SO_2 concentrations as measured by the CEM. The exact nature of the relationship, however, was not one to one as expected. In addition, except for the final study day, a significantly different relationship was found for each group of data. A possible explanation for the differences is presented in the conclusions.

9.0 CONCLUSIONS

Upon reviewing the data it can be seen that each set of measurements is associated with its own unique set of values for the parameters under consideration. In most cases this was unavoidable as there was little control over when and at what time the study was to be performed. Consequently parameters such as ambient temperatures, wind direction and therefore Plumetracker orientation, as well as sun angle were impossible to control.

However, a close examination of the data does point out periods when at least two parameters were nearly identical. Yet during these periods the relationship between the Plumetracker and stack concentration, although consistently linear, differed significantly. The only apparent exception to this is on the last study day when all parameters except for plume opacity and sun angle were held constant and the resulting relationships were nearly equal. One parameter which was also held constant, but which has yet to be discussed is the position of the plume within the field of view.

Upon reviewing the data it was noted that up until December 18, 1984, each set of data was characterised by repositioning the plume within the field of view. This usually ocurred when the Plumetracker was moved closer to or further away from the stack or by simply moving the Plumetracker to compensate for a change in the wind direction. Although the telescopic site enabled the Plumetracker to be positioned accurately, it is doubtful that the exact same position of the plume within the field of view was achieved.

Based upon this observation it is possible to explain why the relationship, which was consistently linear for each data set was found to be different for each data set.

Since the image of the plume within the field of view is imaged directly on to the detector it follows that the location of the plume image on the detector was different for each data set. If the responsivity of the detector was not uniform across its entire surface it follows that different plume image locations on the detector would produce different responses for the same total absorption. Since the detector used in the Plumetracker is a common commercial grade photomultiplier tube it is quite possible that its response is not uniform across its surface.

This theory is also supported by the extemely good correlation observed from the laboratory calibrations. In the laboratory calibration the entire field of view of the Plumetracker was covered by the calibration gas and therefore the image would always be positioned on the same area of the detector.

In summary, the results of the study suggest that parameters such as plume opacity, sun angle etc., can not account for the lack of reproducibility in the data. The position of the Plumetracker, however, seems to be an important factor since each different Plumetracker position resulted in an entirely different relationship between the actual stack concentration and the concentration measured by the Plumetracker. In addition, on the sixth study day when the Plumetracker was not repositioned in between data sets, both data sets show a similar correlation.

10.0 RECOMMENDATIONS

The strong correlation obtained on two seperate ocassions in the laboratory and the strong linear correlations illustrated during the latter part of the study, suggest that the Plumetracker is capable of making reproducible remote measurements of stack SO_2 concentrations. The fact that the relationship found in each case differed from the previous relationship should not detract from the ability of the Plumetracker to make these remote measurements. The inability to achieve reproducible results can be attributed to the positioning of the plume within the field of view which can be compensated for by other means.

To compensate for the aforementioned problem, it is recommended that future measurements employ a true scanning technique. The technique which was described in section 4.2, will result in the plume passing through the entire field of view thereby yielding a truely integrated reading. Since each part of the plume will be exposed to the entire detector surface any non-uniformity in detector response will be averaged out. In addition, this technique will ensure that background zero measurements are made on either side of the plume thereby compensating for any changes in the background sky radiance. The only concern of this method is that the scanning rate must be maintained constant. In order to achieve this constant scan rate it will be necessary to employ a sophisticated motor driven platform to support the Plumetracker.

The use of this technique, however, should improve the reproducibility of any data collected allowing for more detailed study of the parameters which are likely to affect the measurement. Based upon the results of this study these parameters are not, however, expected to contribute significantly to the measurement error.

In summary, the results of this study indicate that with certain improvements in the measuring technique, the Plumetracker could be used to remotely measure stack SO_2 concentrations. The technique employed could also be used for remote measurements of other gases such as NO_2 and possibly ozone. The parameters which might affect the measurement were not, however, fully studied and it is recommended that additional studies be undertaken to assess the impact of these parameters and consequently develop a proven method for the remote measurement of stack emissions.

APPENDIX I

PLUMETRACKER APPLICATIONS NOTES

APPENDIX II

SAMPLE OF PROCESSED DATA

FIGURE 10

FIGURE 11

APPENDIX III

FIELD DATA

TABLE: A

CALIBRATION OF CONTINUOUS EMISSION MONITOR - August 24, 1984

Range Setting: 20

Calibration Setting: 2.5

Zero Setting: 6.3

No.	N2 Flow ml/min	SO2 Flow ml/min	Gas Conc. ppm	C.E.M. Response Volts	Comments
1	14000	0	0	0	Set output to Zero volts
2	"	6.7	480	2.32	Flow unstable
3	"	3.3	235	1.48	" "
4	"	11.8	845	3.52	" "
5	"	17.5	1250	4.96	
6	"	26.6	1895	7.36	
7	"	37.0	2640	9.48	
8	"	20.4	1455	5.92	
9	"	16.0	1140	4.72	
10	"	11.8	845	3.76	
11	"	7.1	505	2.44	
12	"	4.0	285	1.72	
13	"	2.7	190	1.32	
14	"	0	0	0	
15	70	0	0	0	

FIGURE A

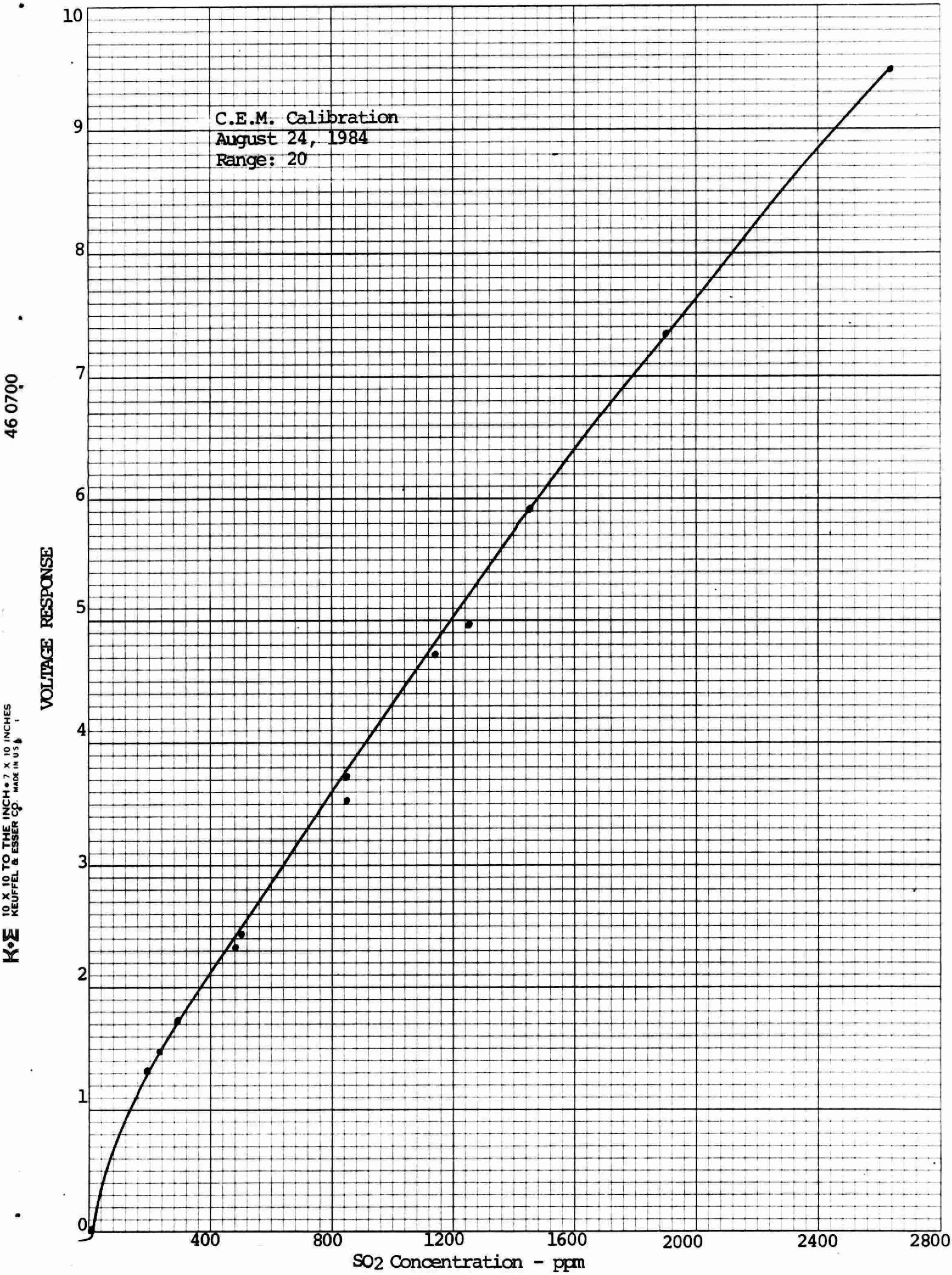

C.E.M. Calibration
August 24, 1984
Range: 20
VOLTAGE RESPONSE
SO2 Concentration - ppm
0
1
2
3
4
5
6
7
8
9
10
400
800
1200
1600
2000
2400
2800
46 0700
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TABLE: B

CALIBRATION OF PLUMETRACKER - AUGUST 24, 1984

Peak Setting :3
Signal Amplitude :6 volts
Cell Pathlength :10 cm

No.	N2 Flow ml/min	SO2 Flow ml/min	Gas Conc. ppm-M	Response Volts	Comments
1	4625	0	0	0	Set to Zero Volts
2	"	5.0	110	.36	Flow Unstable
3	"	7.3	160	.52	
4	"	11.1	240	.80	
5	"	14.5	315	1.04	
6	"	17.7	380	1.28	
7	"	24.6	530	1.72	
8	"	30.6	660	2.24	
9	"	42.5	910	3.04	
10	"	57.2	1220	3.88	
11	"	73.0	1555	4.88	
12	3587	73.0	1995	6.32	
13	2784	73.0	2555	8.00	
14	2124	73.0	3325	--	Output Exceeded 10 volt full scale
15	2124	49.8	2290	7.32	

FIGURE B

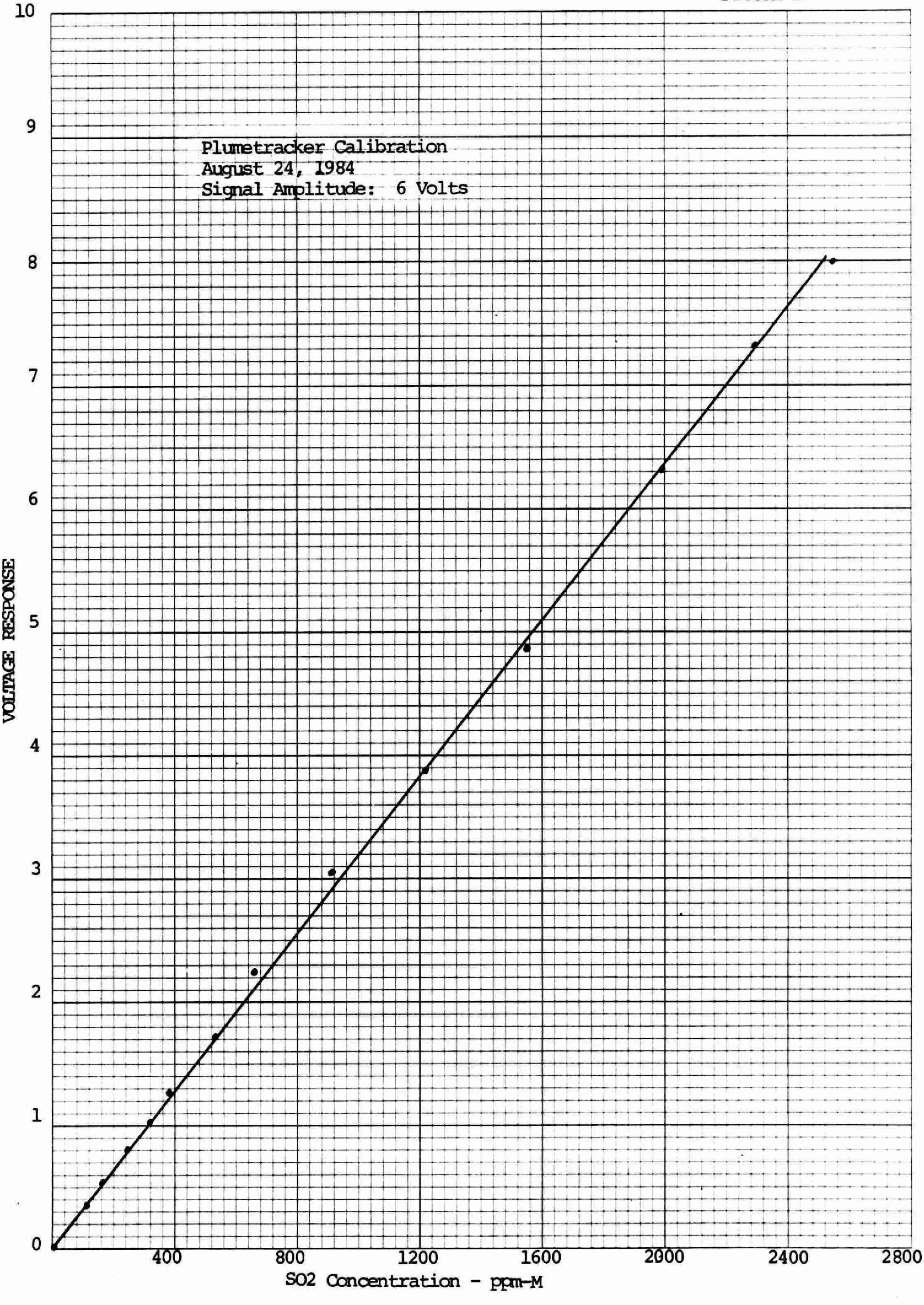
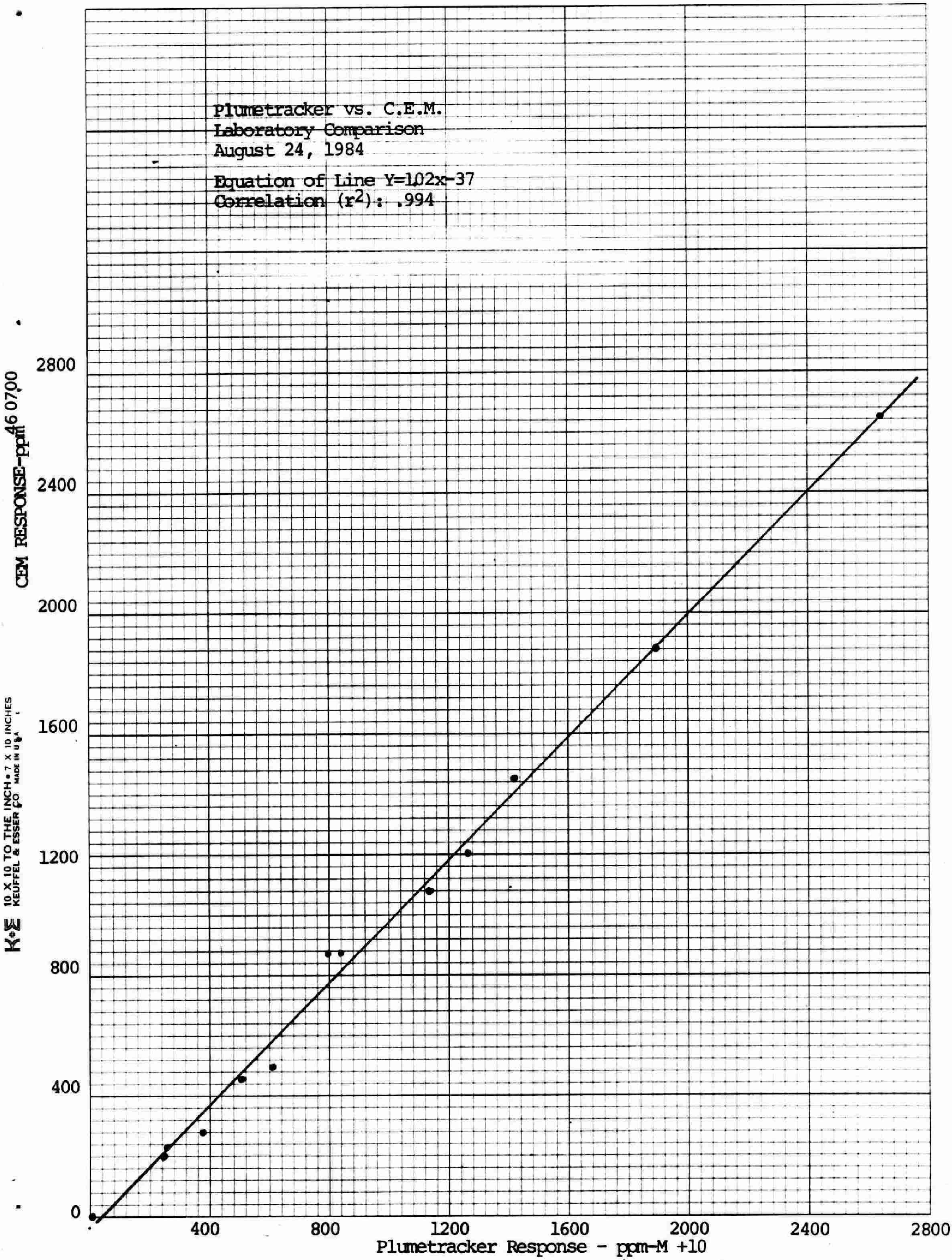

Plumetracker Calibration
August 24, 1984
Signal Amplitude: 6 Volts
VOLTAGE RESPONSE
0
1
2
3
4
5
6
7
8
9
10
400
800
1200
1600
2000
2400
2800
SO2 Concentration - ppm-M

TABLE: C

PLUMETRACKER VS. C.E.M. - RESPONSE COMPARISON - August 24, 1984

No.	Test Gas Concentration ppm	C.E.M. Response ppm	Plumetracker Response ppm-M	Comments
1	0	0	0	
2	480	460	50	Low Pt. Response
3	235	235	25	" "
4	845	880	79	
5	1250	1200	126	
6	1895	1890	189	
7	2640	2645	264	
8	1455	1455	141	
9	1140	1120	114	
10	845	880	84	
11	505	500	63	Low Pt. Response
12	285	280	37	" "
13	190	200	25	" "

FIGURE C


Plumetracker vs. C.E.M.
Laboratory Comparison
August 24, 1984
Equation of Line Y=1.02x-37
Correlation (r^2): .994
CEM RESPONSE-ppm
Plumetracker Response - ppm-M +10
0
400
800
1200
1600
2000
2400
2800
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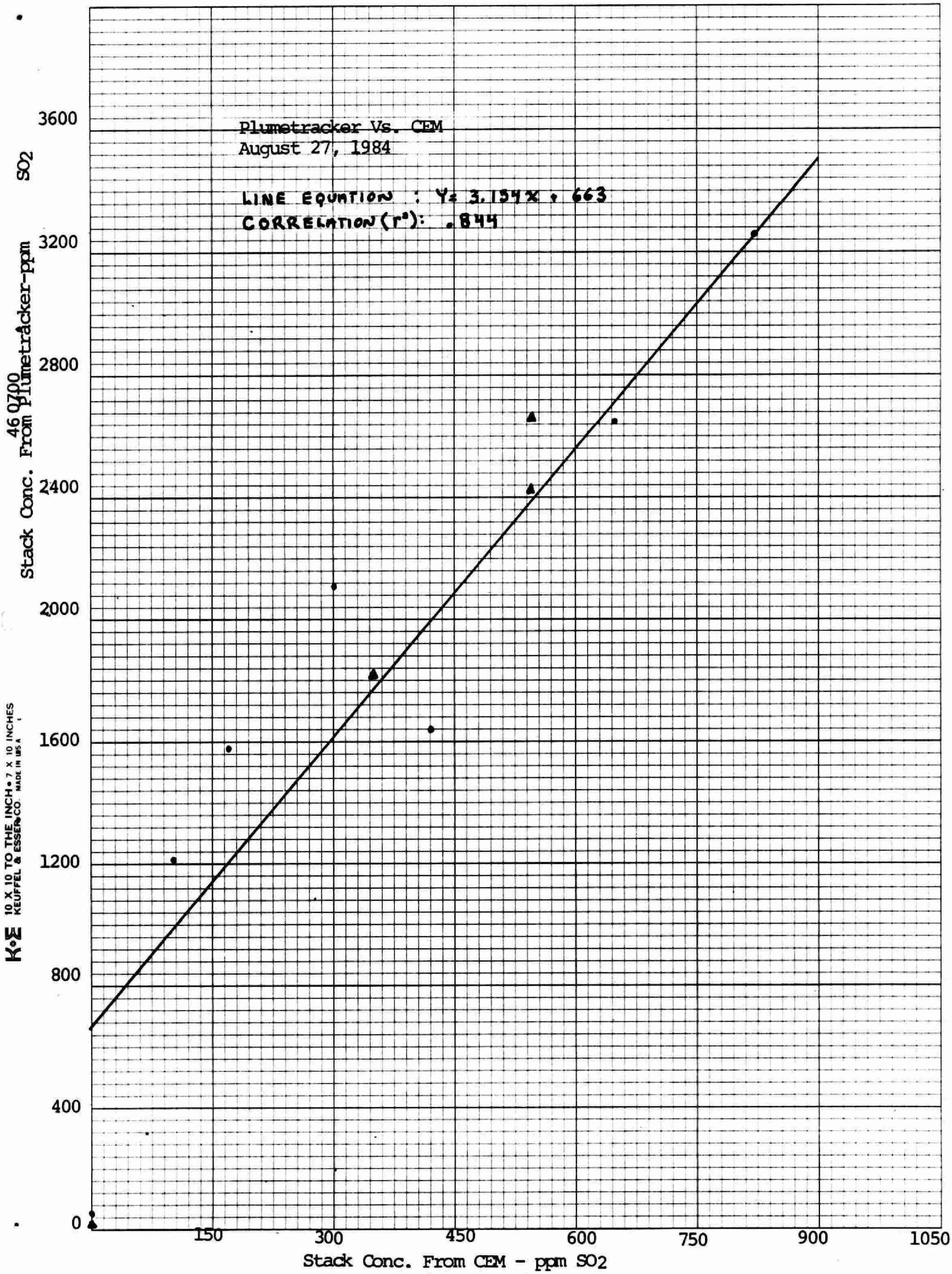
STACKSCANNER FIELD SUMMARY DATE: August 27 TABLE NO. D

Wind Direction: South-West Wind Speed: >25Km/Hr. Temperature: 25 Degrees C

Sky Conditions: Blue Sky with Some Light Cloud Cover

Run #	Time	Length of Run sec.	Zero Volts	Span ppm-M /volt	AGC Level volts	Dist. to Stack Meters	Plume Rise cm.	Plume Opacity	Stack Conc. ppm	Pl.Tracker Conc. ppm	FOV Cover-age %	Comments	Valid Run
1	14.11	60	3.04	366	5.80	19.2	---	Zero	0	20	30		Yes
2	14.19	"	2.89	--	--	"	---	"	350	1825	"		"
3	14.23	"	2.89	--	--	"	---	"	545	2670	"		"
4	14.33	"	2.92	--	5.40	"	---	"	545	2420	"	Moved Location	"
5	15.05	"	2.07	--	--	44	---	"	300	---	13	Reset Zero	No
6	15.10	"	2.14	--	--	"	---	"	300	2115	"		Yes
7	15.16	"	2.13	358	--	"	---	"	170	1580	"		"
8	15.21	90	2.23	--	4.85	"	---	"	100	1205	"		"
9	15.25	"	2.18	--	--	"	---	"	0	45	"		"
10	15.31	"	2.19	--	--	"	---	"	400	---	"	Prob with HP-85	No
11	15.38	"	2.09	--	--	"	---	"	420	1640	"		Yes
12	15.44	"	2.15	--	4.25	"	---	"	650	2550	"		"
13	15.49	"	2.11	--	--	"	---	"	820	3265	"		"

FIGURE D



Plumetracker Vs. CEM
August 27, 1984
LINE EQUATION : Y= 3.154X + 663
CORRELATION (r²): .844
Stack Conc. From Plumetracker-ppm SO2
Stack Conc. From CEM - ppm SO2
0
400
800
1200
1600
2000
2400
2800
3200
3600
150
300
450
600
750
900
1050
46 0700
K•E 10 X 10 TO THE INCH • 7 X 10 INCHES
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STACKSCANNER FIELD SUMMARY   DATE: August 29   TABLE NO. E

Page 1 of 2

Wind Direction: West Wind Speed: >15Km/Hr. Temperature: 20-25°C

Sky Conditions: Almost Total Cloud Cover Although Very Thin Layer

Run #	Time	Length of Run Sec.	Zero Volts	Span ppm-M /volt	AGC Level Volts	Dist. to Stack Meters	Plume Rise cm.	Plume Opacity	Stack Conc. ppm	Pl.Tracker Conc. ppm	FOV Coverage%	Comments	Valid Run
1	10:52	30	3.23	346	3.30	19	—	Zero	0	-55	30	Pt. Moved In Run	No
2	11:05	120	2.88	—	"	"	—	"	0	-36	"	Zero Above Stack	Yes
3	11:13	120	2.83	—	"	"	—	"	0	-20	"		"
4	11:21	60	2.72	—	3.35	"	—	"	150	154	"		"
5	11:27	"	2.64	—	"	"	—	"	260	343	"		"
6	11:34	"	2.58	—	"	"	—	"	415	346	"		"
7	11:50	"	2.35	—	3.20	9.6	—	"	115	78	55	Moved Location	"
8	11:57	"	2.78	340	3.60	"	—	"	295	648	"	Reset Zero	"
9	12:04	"	2.41	—	3.80	"	—	"	315	691	"		"
10	12:16	"	2.31	378	3.80	"	—	"	150	586	"		"
11	12:19	"	2.33	—	"	"	—	"	315	1037	"		"
12	12:22	"	2.31	—	"	"	—	"	415	1037	"		"
13	12:25	"	2.34	—	"	"	—	"	450	1091	"		"
14	12:28	"	2.39	—	"	"	—	"	115	348	"		"
15	12:31	"	2.36	—	"	"	—	"	30	151	"		"
16	12:37	"	2.35	358	3.90	"	—	"	35	173	"		"
17	12:57	"	3.58	—	—	"	—	"	—	—	"	Prob. With C.E.M.	No
18	13:04	"	3.91	—	—	"	—	"	—	—	"	" "	"

MONITEQ

STACKSCANNER FIELD SUMMARY DATE: August 29 TABLE NO. E

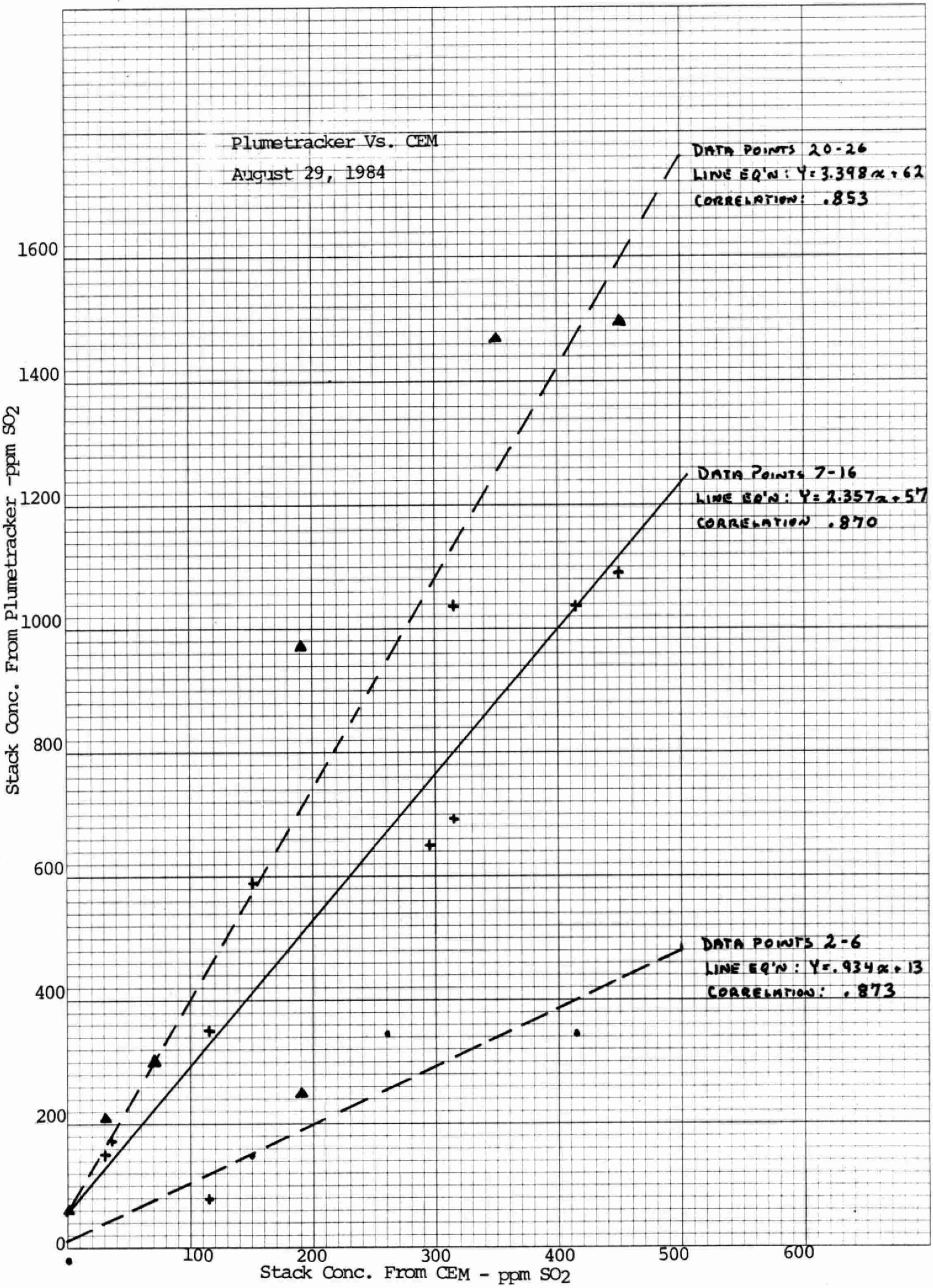
Page 2 of 2

Wind Direction: West Wind Speed: >15Km/Hr. Temperature: 20→25°C

Sky Conditions: Almost Total Cloud Cover Although Very Thin Layer

Run #	Time	Length of Run Sec.	Zero Volts	Span ppm-M /volt	AGC Level Volts	Dist. to Stack Meters	Plume Rise cm.	Plume Opacity	Stack Conc. ppm	Pl.Tracker Conc. ppm	FOV Cover-age%	Comments	Valid Run
19	13:09	60	3.52	--	--	9.6	--	Zero	--	--	55	Prob. With C.E.M.	No
20	13:38	"	3.06	355	3.30	20.5	--	"	0	59	27	Moved Location	Yes
21	13:43	"	3.07	--	--	"	--	"	30	210	"		"
22	13:48	"	3.10	--	--	"	--	"	190	255	"		"
23	13:54	"	3.10	--	--	"	--	"	450	1493	"		"
24	13:57	"	3.03	--	3.30	"	--	"	350	1472	"		"
25	14:00	"	3.14	--	--	"	--	"	190	972	"		"
26	14:06	"	3.07	--	3.30	"	--	"	70	324	"		"
27	14:13	"	3.11	--	3.30	"	--	"	0	--	"	Tape Full	No

FIGURE E


Plumetracker Vs. CEM
August 29, 1984
DATA POINTS 20-26
LINE EQ'N: Y=3.398x+62
CORRELATION: .853
DATA POINTS 7-16
LINE EQ'N: Y=2.357x+57
CORRELATION .870
DATA POINTS 2-6
LINE EQ'N: Y=.934x+13
CORRELATION: .873
Stack Conc. From Plumetracker -ppm SO_2
Stack Conc. From CEM - ppm SO_2
0
200
400
600
800
1000
1200
1400
1600
100
200
300
400
500
600
46 0700
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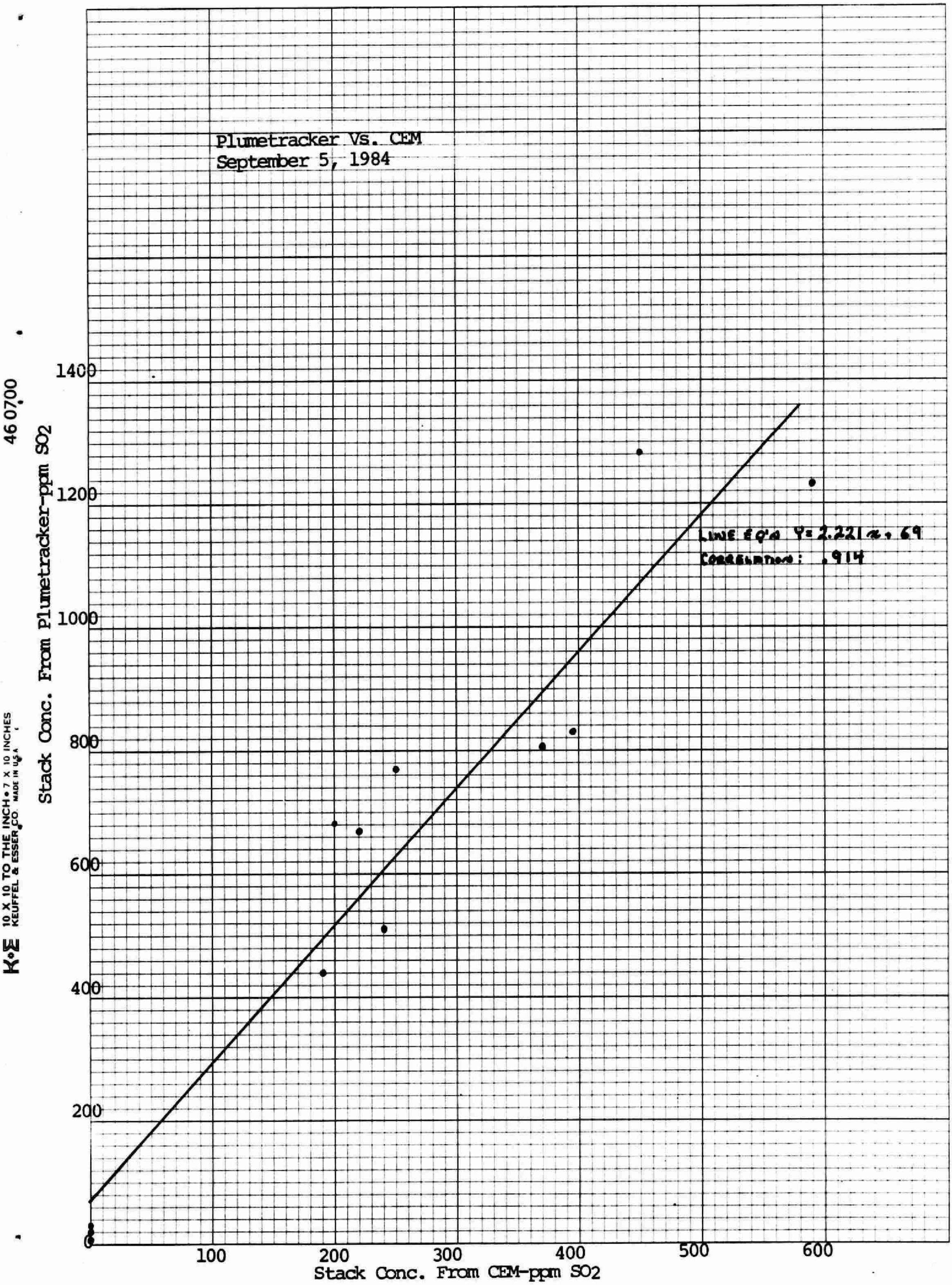
STACKSCANNER FIELD SUMMARY DATE: September 5 TABLE NO. F

Wind Direction: North Wind Speed: >10Km/Hr. Temperature: 20°C

Sky Conditions: Large Cumulus Clouds Present During Study-Plume Rise Less Than 2 Cm. in All Runs

Run #	Time	Length of Run Sec.	Zero Volts	Span ppm-M /volt	AGC Level Volts	Dist. to Stack Meters	Plume Rise cm.	Plume Opacity	Stack Conc. ppm	Pl.Tracker Conc. ppm	FOV Coverage%	Comments	Valid Run
1	12:12	30	.34	134	3.00	7.6	0-2	L	0	29	68	Clouds Affected	No
2	12:23	120	.34	--	--	"	"	L	0	-196	"	Pt. Signal	No
3	12:36	120	.39	139	--	"	"	L	0	7	"	Small Plume Rise	Yes
4	12:44	60	.43	--	--	"	"	M	220	671	"	" "	"
5	12:51	"	.43	--	--	"	"	M	240	509	"	" "	"
6	12:55	"	.43	--	3.80	"	"	M	370	805	"	" "	"
7	13:01	"	.41	--	--	"	"	M	190	441	"	" "	"
8	13:04	"	.44	--	--	"	"	M	200	706	"	" "	"
9	13:10	"	.39	--	--	"	"	L	395	829	"	" "	"
10	13:16	"	.43	--	--	"	"	L	590	1236	"	" "	"
11	13:19	"	.47	--	--	"	"	L	450	1283	"	" "	"
12	13:23	"	.42	--	--	"	"	H	250	768	"	" "	"
13	13:27	"	.44	136	--	"	"	H	0	80	"	Cloud In FOV	No
14	13:30	"	.41	--	--	"	"	H	0	19	"	Low Plume Rise	Yes
15	13:35	"	.45	--	--	"	"	H	0	12	"	" "	"

FIGURE F


Plumetracker Vs. CEM
September 5, 1984
LINE EQ'N Y = 2.221 x + 69
CORRELATION: .914
1400
1200
1000
800
600
400
200
0
100
200
300
400
500
600
Stack Conc. From Plumetracker-ppm SO2
Stack Conc. From CEM-ppm SO2
10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 0700

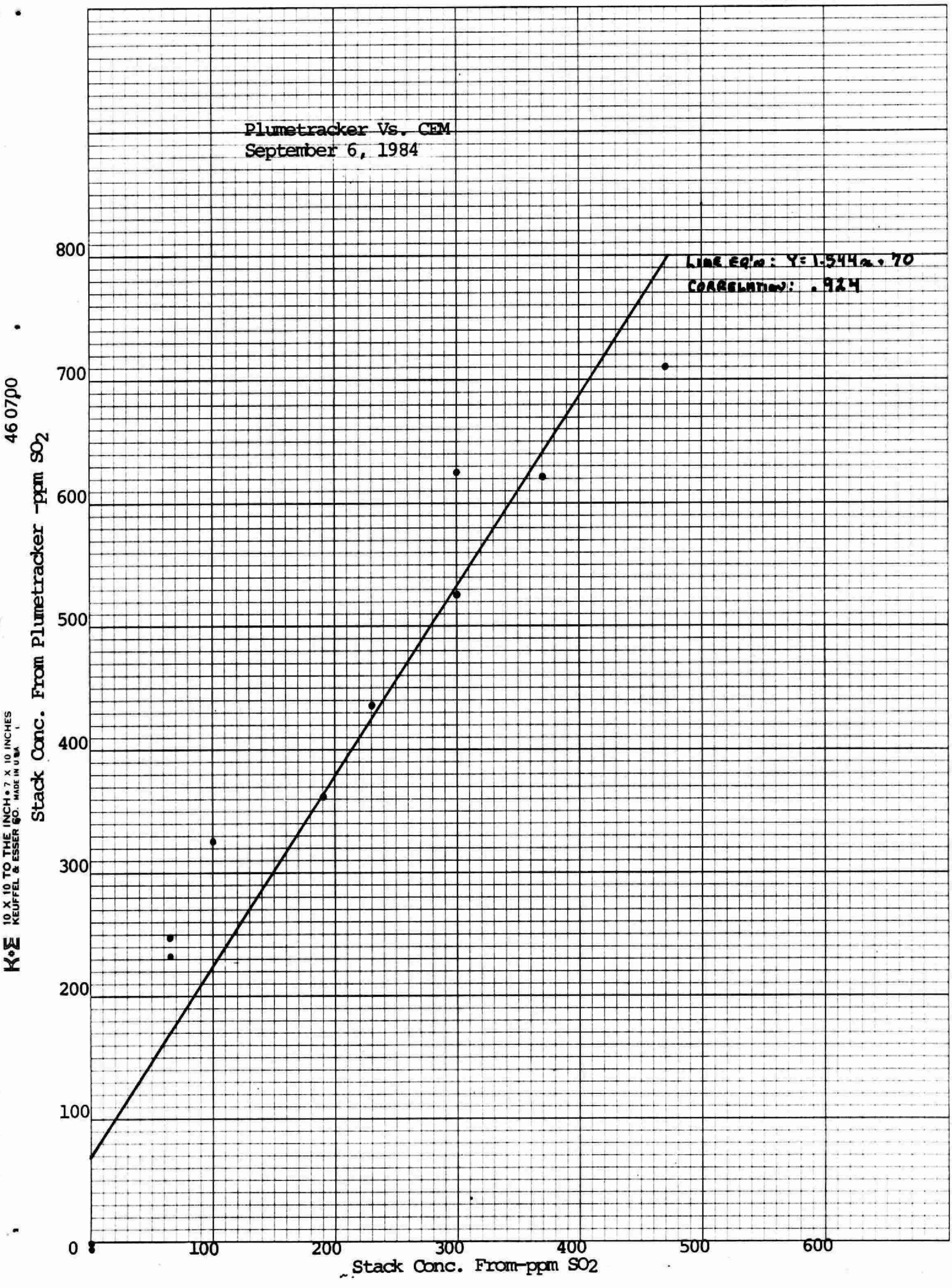
STACKSCANNER FIELD SUMMARY DATE: September 6, 1984 TABLE NO. G

Wind Direction: West Wind Speed: >5 Km/Hr. Temperature: 15°C

Sky Conditions: Slightly Overcast With Light Clouds. Wind Increased Later in Day. Plume Rise During Runs Was Variable

Run #	Time	Length of Run Sec.	Zero Volts	Span ppm-M /volt	AGC Level Volts	Dist. to Stack Meters	Plume Rise cm.	Plume Opacity	Stack Conc. ppm	Pl.Tracker Conc. ppm	FOV Cover-age%	Comments	Valid Run
1	10:15	30	--	--	--	5.3	--	--	--	--	91	Prob. With PT.	No
2	10:22	30	--	--	--	"	--	--	--	--	"	"	No
3	10:36	30	--	--	--	"	--	--	--	--	"	"	No
4	10:42	60	.69	119	5.80	"	--	Zero	0	-9	"		Yes
5	10:45	"	.67	--	--	"	3	L	0	-3	"		"
6	10:49	"	.71	--	--	"	3	L	0	-12	"		"
7	10:59	"	.71	--	--	"	1 to 3	L	300	526	"		"
8	11:10	"	.62	--	--	"	"	L	100	327	"		"
9	11:15	"	.67	--	--	"	"	L	65	232	"		"
10	11:23	"	.69	122	6.00	"	"	L	230	437	"		"
11	11:27	"	.65	--	--	"	5	L	190	361	"		"
12	11:34	"	.67	--	--	"	1 to 3	L	370	621	"		"
13	11:42	"	.62	--	7.00	"	1 to 2	L	470	710	"		"
14	11:50	"	.73	--	--	"	1	M	65	248	"		"
15	12:07	"	.73	126	--	"	1	M	300	626	"		"
16	12:24	"	.70	--	--	"	Zero	--	260	1098	"	No Plume Rise	No

FIGURE G


Plumetracker Vs. CEM
September 6, 1984
LINE EQ'N: Y=1.544x+70
CORRELATION: .924
Stack Conc. From Plumetracker -ppm SO2
Stack Conc. From-ppm SO2
0
100
200
300
400
500
600
700
800
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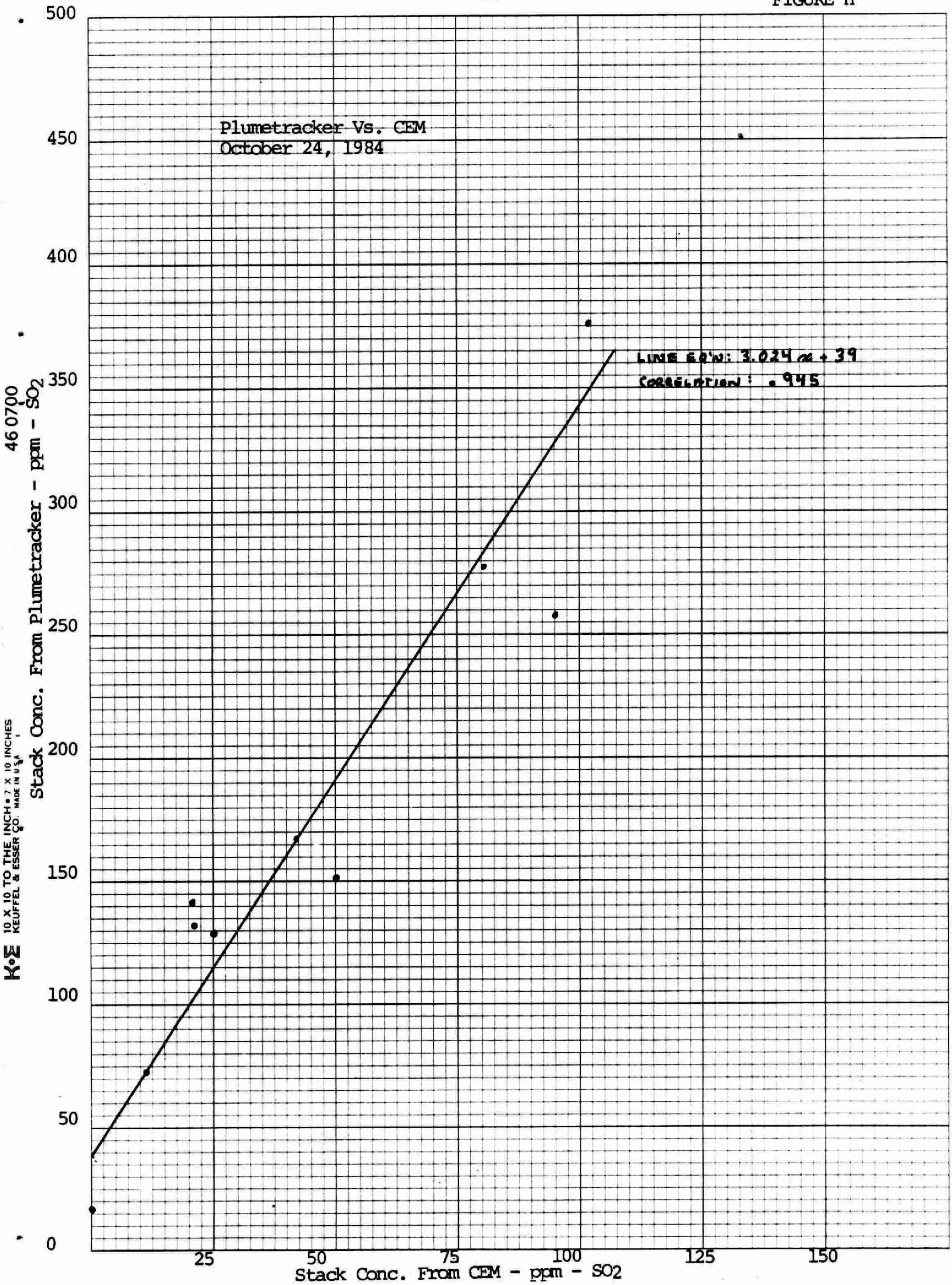
STACKSCANNER FIELD SUMMARY DATE: October 24, 1984 TABLE NO. H

Wind Direction: -- Wind Speed: Zero Temperature: 5 to 8oC

Sky Conditions: Clear Blue - No Wind

Run #	Time	Length of Run Sec.	Zero Volts	Span ppm-M /volt	AGC Level Volts	Dist. to Stack Meters	Plume Rise cm.	Plume Opacity	Stack Conc. ppm	Pl.Tracker Conc. ppm	FOV Cover-age%	Comments	Valid Run
1	9:17	30	1.17	114	3.45	6.4	5	Low	0	17	78		Yes
2	9:22	"	1.37	--	--	"	"	"	21	141	"		"
3	9:27	"	1.44	--	4.20	"	"	"	22	131	"		"
4	9:32	"	1.46	--	5.20	"	"	"	25	129	"		"
5	9:38	"	1.57	103	6.80	"	"	"	12	75	"		"
6	9:45	"	1.22	--	4.90	"	3	"	42	168	"	Reset Zero /AGC	"
7	9:51	"	1.29	--	5.65	"	"	"	50	151	"		"
8	10:03	"	1.50	--	3.40	"	5	"	81	278	"	Reset Zero /AGC	"
9	10:09	"	1.11	108	3.80	"	"	"	95	257	"		"
10	10:13	"	1.23	--	4.35	"	"	"	102	376	"		"
11	10:18	"	1.27	--	5.15	"	"	"	146	515	"		"

FIGURE H



Plumetracker Vs. CEM
October 24, 1984
LINE EQ'N: 3.024 x + 39
CORRELATION: .945
Stack Conc. From Plumetracker - ppm - SO_2
Stack Conc. From CEM - ppm - SO2
500
450
400
350
300
250
200
150
100
50
0
25
50
75
100
125
150
K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 0700

TABLE:I

CALIBRATION OF CONTINUOUS EMISSION MONITOR - November 19, 1984

Range Setting :20
Calibration Setting:5.5
Zero Setting :1.0

No.	N_2 Flow ml/min	SO_2 Flow ml/min	Gas Conc. ppm	C.E.M. Response Volts	Comments
1	14000	0	0	0	Set Output to Zero
2	"	5.8	415	1.84	
3	"	8.5	605	3.08	
4	"	11.2	800	3.68	
5	"	16.9	1205	5.08	
6	"	24.0	1710	6.88	
7	"	31.0	2210	8.44	
8	"	37.3	2660	9.44	
9	"	3.7	265	1.08	
10	Field Standard No. 1			1.96	Conc.=400ppm

FIGURE I

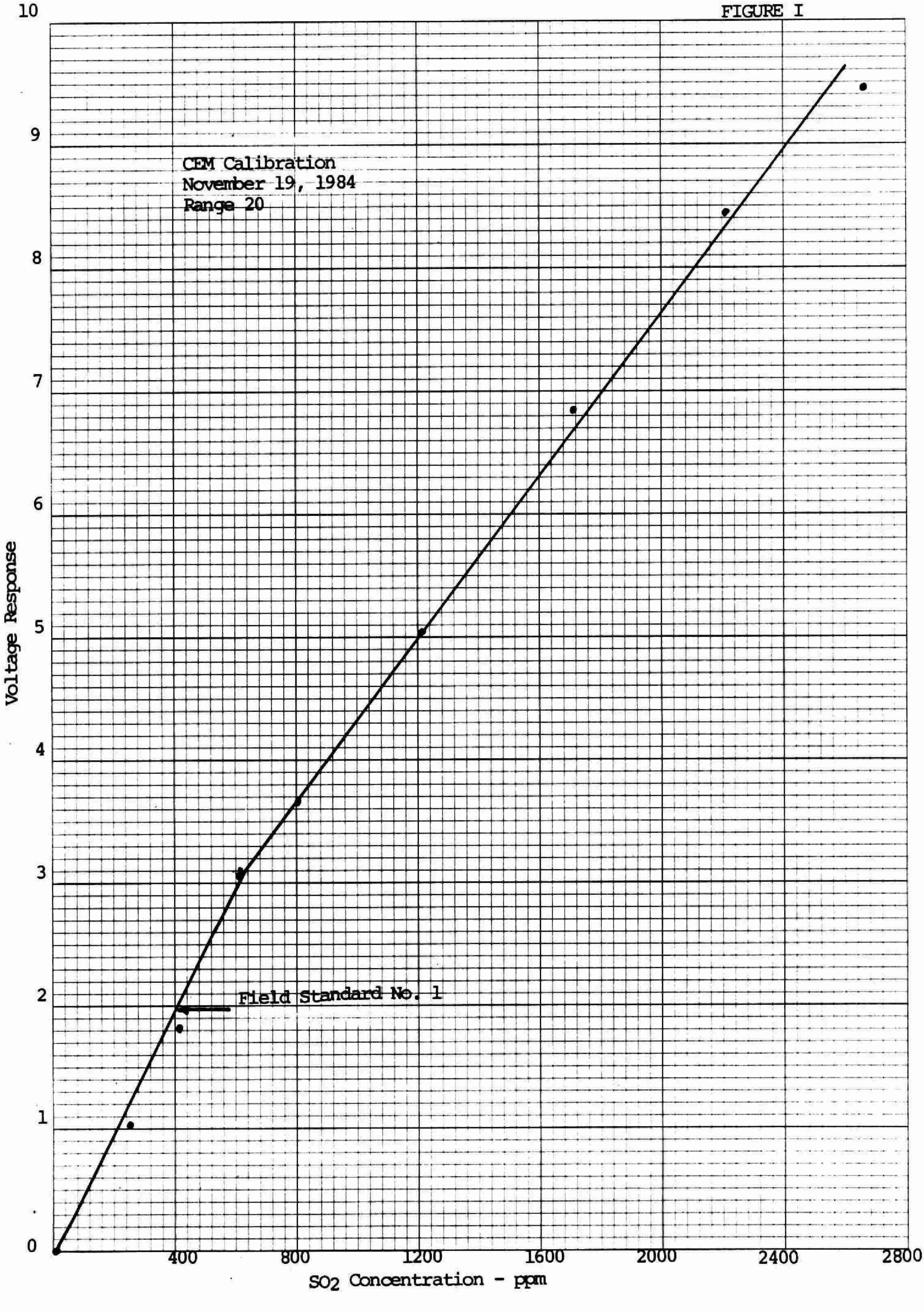

CEM Calibration
November 19, 1984
Range 20
Field Standard No. 1
Voltage Response
0
1
2
3
4
5
6
7
8
9
10
400
800
1200
1600
2000
2400
2800
SO2 Concentration - ppm

TABLE: J

CALIBRATION OF PLUMETRACKER - November 19, 1984

Peak Setting :7
Signal Amplitude :6 volts
Cell Path Length :10 cm.

No.	N_2 Flow ml/min	SO_2 Flow ml/min	Gas Conc. ppm-M	Response Volts	Comments
1	14000	0	0	0	Set Output to Zero
2	"	5.8	40	.60	
3	"	8.5	60	1.10	
4	"	11.2	80	1.30	
5	"	16.9	120	1.85	
6	"	24.0	170	2.65	
7	"	31.0	220	3.35	
8	"	37.3	265	3.80	
9	"	36.2	255	3.70	
10	11750	"	310	4.50	
11	9400	"	385	5.60	
12	7200	"	500	7.30	
13	6000	"	600	8.55	
14	4800	"	750	10.00	
15	Field Standard No. 2			8.00	Conc.=5550ppm

FIGURE J

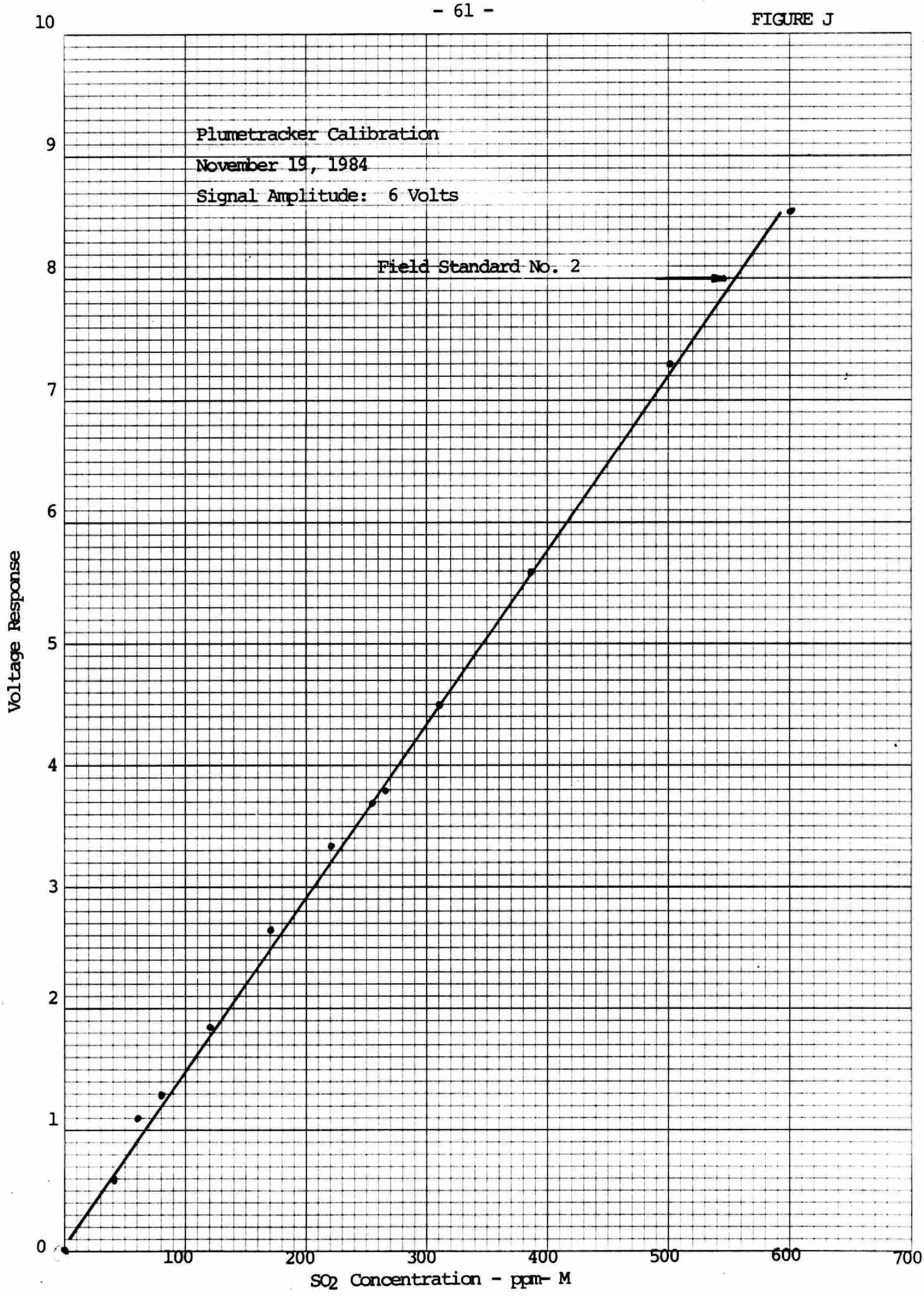
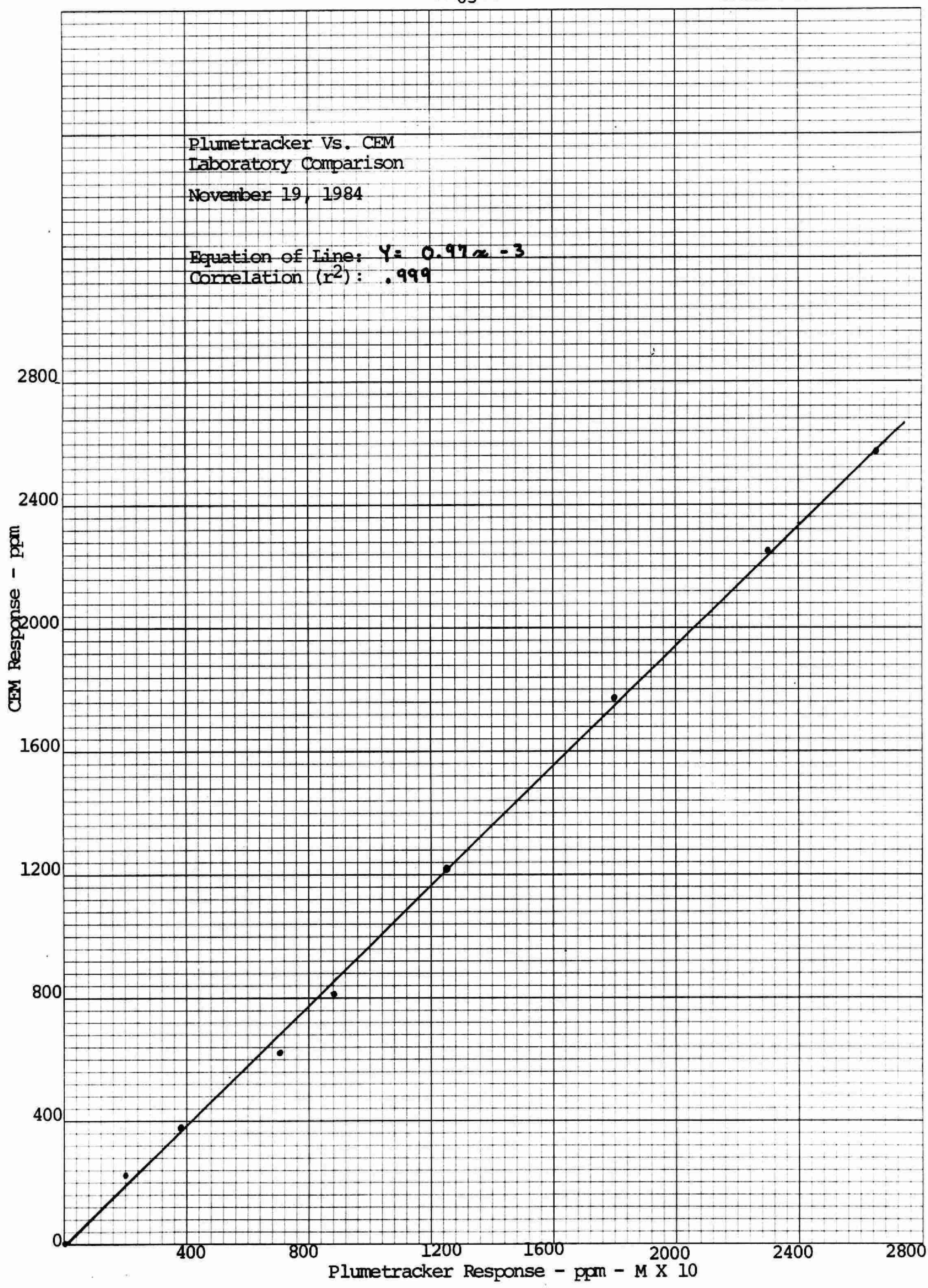

Plumetracker Calibration
November 19, 1984
Signal Amplitude: 6 Volts
Field Standard No. 2
Voltage Response
SO2 Concentration - ppm- M
0
1
2
3
4
5
6
7
8
9
10
100
200
300
400
500
600
700

TABLE: K

PLUMETRACKER VS. C.E.M. - RESPONSE COMPARISON - November 19, 1984

No.	Test Gas Concentration ppm	C.E.M. Response ppm	Plumetracker Response ppm - M	Comments
1	0	0	0	
2	265	230	20	Low Pt. Response
3	415	380	38	" "
4	605	630	71	" "
5	800	810	88	
6	1205	1220	125	
7	1710	1770	180	
8	2210	2250	230	
9	2660	2550	265	

FIGURE K


Plumetracker Vs. CEM
Laboratory Comparison
November 19, 1984
Equation of Line: Y= 0.97x -3
Correlation (r^2): .999
CEM Response - ppm
Plumetracker Response - ppm - M X 10
0
400
800
1200
1600
2000
2400
2800

STACKSCANNER FIELD SUMMARY DATE: December 18 TABLE NO. L

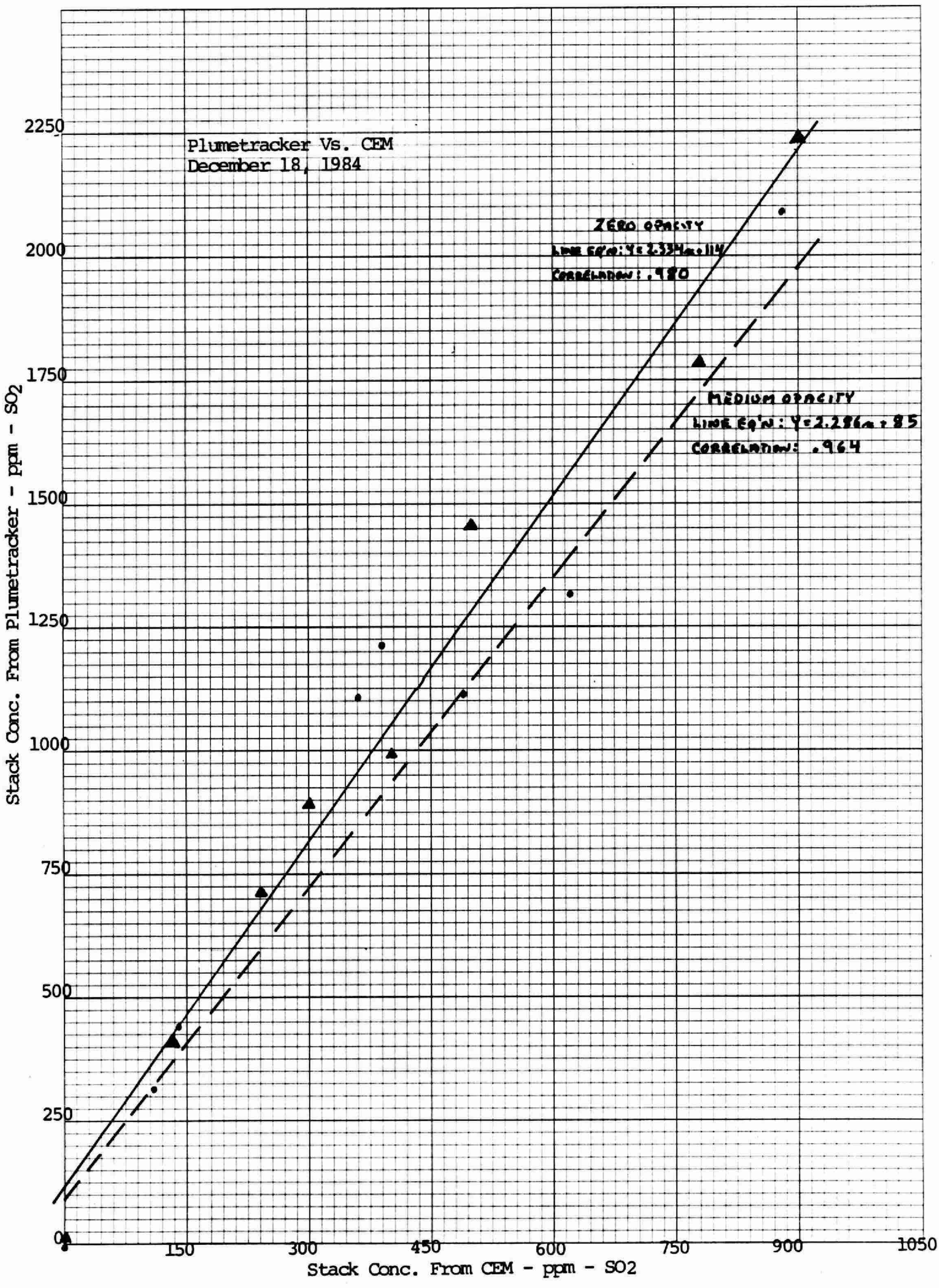
Wind Direction: West Wind Speed: >10 Km/Hr. Temperature: 3°C

Sky Conditions: Heavily But Uniformly Overcast - Runs 1 and 2 Not Valid-Problems With Windscreen Alignment

Run #	Time	Length of Run Sec.	Zero Volts	Span ppm-M /volt	AGC Level Volts	Dist. to Stack Meters	Plume Rise cm.	Plume Opacity	Stack Conc. ppm	Pl.Tracker Conc. ppm	FOV Cover-age%	Comments	Valid Run
3	11:36	30	.27	63	3.30	6	5	M	0	9	83		Yes
4	11:40	"	.22	--	---	"	"	"	360	1108	"		"
5	11:44	"	.26	--	---	"	"	"	390	1215	"		"
6	11:47	"	.22	--	3.45	"	"	"	620	1320	"		"
7	11:51	"	.21	--	---	"	"	"	110	319	"		"
8	11:55	"	.25	--	---	"	"	"	490	1114	"		"
9	12:01	"	.24	--	3.75	"	"	"	880	2087	"		"
10	12:18	"	.19	65	---	"	"	"	140	437	"		"
11	12:21	"	.42	--	---	"	"	"	0	-5	"	Reset Zero	"
12	12:28	"	.44	--	---	"	"	Zero	240	715	"		"
13	12:32	"	.51	--	---	"	"	"	400	988	"		"
14	12:38	"	.50	--	---	"	"	"	---	---	"	Prob. With CEM	No
15	13:03	"	.66	63	4.30	"	"	"	0	12	"		Yes
16	13:08	"	.59	--	---	"	"	"	300	892	"		"
17	13:12	"	.57	--	---	"	"	"	500	1456	"		"
18	13:17	"	.52	--	---	"	"	"	780	1783	"		"
19	13:22	"	.54	--	---	"	"	"	900	2240	"		"
20	13:25	"	.54	--	---	"	"	"	130	413	"		"

MONITEQ

FIGURE L


Plumetracker Vs. CEM
December 18, 1984
ZERO OPACITY
LINE EQ'N: Y=2.334x+114
CORRELATION: .980
MEDIUM OPACITY
LINE EQ'N: Y=2.286x+85
CORRELATION: .964
Stack Conc. From Plumetracker - ppm - SO2
0
250
500
750
1000
1250
1500
1750
2000
2250
Stack Conc. From CEM - ppm - SO2
0
150
300
450
600
750
900
1050